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AD-A228 661

Contract No.: DAMD17-89-C-9150

Title: **ADDITIONAL EFFORT IN MODELING OF THE NON-AUDITORY EFFECTS OF BLAST**

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PI Address: JAYCOR, 11011 Torreyana Road, San Diego, CA 92121

Report Date: 31 August 1990

Type of Report: Mid-Term Report

Prepared for: U. S. Army Medical Research and Development Command
Fort Detrick
Frederick, Maryland 21702-5012

Distribution Statement: Approved for public release; distribution unlimited

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS: N/A

2a. SECURITY CLASSIFICATION AUTHORITY: N/A

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE: N/A

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for Public Release; Distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION: JAYCOR
Applied Sci. & Engr. Technol. Group

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code): 11011 Torreyana Rd.
San Diego, CA 92121-1190

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: U. S. Army Medical Res. & Devel. Cmd.

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: DAMD17-89-C-9150

8c. ADDRESS (City, State, and ZIP Code): Fort Detrick
Frederick, MD 21702-5012

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	3M1-62787A878	AB	002

11. TITLE (Include Security Classification): **(U) Additional Effort in Modeling of the Non-Auditory Effects of Blast**

12. PERSONAL AUTHOR(S): James H. Stuhmiller

13a. TYPE OF REPORT: Mid-Term

13b. TIME COVERED: FROM 9/30/89 - 7/30/90

14. DATE OF REPORT (Year, Month, Day): 1990 August 31

15. PAGE COUNT: 76

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
06	03	
06	04	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): RA 3; Blast Injury; Modeling; Thorax/Lung

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The scientific progress will be reported by subtask as contained in our original proposal. In mid-August we gave a detailed briefing to Dr. Kenneth Dodd of WRAIR on the technical accomplishments of the project to date and to COL Sedge, RAD-3, on the technical and programmatic progress.

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20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

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22c. OFFICE SYMBOL: SGRD-RMI-S

DD FORM 1473, 84 MAR

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FOREWORD

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_____ For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 45 CFR 46.

_____ In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institutes of Health.

9/5/90

PI Signature Date

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Scientific Progress

The scientific progress will be reported by subtask as contained in our original proposal. In mid-August we gave a detailed briefing to Dr. Kenneth Dodd of WRAIR on the technical accompishments of the project to date and to Col. Sedge, RAD-3, on the technical and programmatic progress. The materials presented in those briefings are attached.

Research Topic 1: Pathology of Lung Injury

Task 1. Construction of a database for lung injury pathology

Subtask 1.1 Database specification. Working together with the WRAIR COR, we have formulated a specification of the entries to be included in the pathology database. That specification was submitted with the 1st quarterly progress report. The computer program for entering new pathology data will follow this format.

The existing Albuquerque pathology data collected and analyzed under this Task, however, does not include this level of detail. Consequently, this data must be characterized differently to avoid introducing inordinate speculation. A compromise was arrived at in which a new entry is included for each anatomical location (larynx, trachea, five lung lobes, and 13 sections of the gastrointestinal tract) that indicates injury on a yes/no basis. This will allow the existing data to be correlated and will not conflict with more complete data entered later.

After all of the pictorial data on lung injury has been analyzed, we will work together with the WRAIR COR to refine the injury description in each of the lung lobes.

This subtask is now complete.

Subtask 1.2 Software development. The pathology database software consists of two parts. The first is a relational database for the entries in the specification sheet and related data on the blast exposure (text data). The second is a program for entering, retrieving, and manipulating graphical representations of the lung necropsy pictures.

The software to enter, modify, and browse the text data associated with the Albuquerque tests has been written in FORTRAN and C Languages using the commercially available package of database routines made by INFORMIX. The database now includes all of the blast and pathology entries necessary to store the existing data. It was necessary to add database records to store lengthy comments that were part of the Albuquerque posting sheets.

This part of the subtask is now complete.

Future animal tests will report necropsy data according to the newly designed, more quantitative pathology sheets. We are modifying the database software to allow the user to enter, modify, and browse through data in this form. We understand that WRAIR would like to re-score all of the old data into the new format, so that there might eventually be a single, consistent data format.

Subtask 1.3 Compilation of data. All of the data, magnetic tape, necropsy scoring sheets, strip chart records, field notebook records, photographs, and written reports that are available to us have been compiled and cataloged. There are two areas where data is incomplete: digitized pressure traces from the "double peak" study and the original pathology sheets from one of the Albuquerque tests. The blast data requires the tape recorder used at the Kirtland Test Site, while EG&G has the pathology data. WRAIR has requested both from the operators of the Test Site. Since the data has not been made available soon, we will not be including it in this version of the database.

The pathology data has been organized by test series and by animal within test series. All photographs have been sequentially numbered so they can be cross-referenced within the database. We have made high-quality color reproductions of all of the data and returned the original data to WRAIR for safekeeping.

The data comprises tests of over 600 animals and the hardcopy form consists of over 5000 pages of text and pictures.

This subtask is complete.

Subtask 1.4 Qualification of the data. All of the data has been reviewed for consistency and completeness. No obvious inconsistencies have been found, although anomalies have been seen, for example, one animal severely injured when five others with the same exposure are not injured. These differences may reflect animal variability or may later be found to be a reporting error. Resolution of these questions must await the findings of the model tasks.

The data is satisfactorily complete. The earlier tests were less detailed in reporting pathology, but that was expected, since it was not a requirement at the time. The pathology data that EG&G has refused to release is an obvious problem, but it affects the graphical aspects rather than the text entries.

This subtask is complete.

Subtask 1.5 Data entry. All of the pathology text data that has been made available to us has been entered.

This part of the subtask is complete.

We will work with the WRAIR COR during the next quarter to determine the needs for an electronic form of the graphical and photographic data.

Subtask 1.6 Reporting and distribution. Delivery of these items is not planned for another year, however, the database has already answered some immediate needs. At the request of the WRAIR COR we analyzed the existing entries to determine the probable validity of the Bowen correlation in predicting injury. The preliminary results show that injury occurs at blast levels a factor of two or three lower than that predicted by the Bowen curve for threshold lung injury.

Subtask 1.7 Database maintenance. Work has not begun on this subtask.

Task 2. Multi-dimensional model of thorax response

Subtask 2.1 Multi-dimensional free-field load description. Load data taken in the free-field from Lambdroid and chest wall mounted gages and well as previous EITACC calculational results have been compiled. The results support the following correlation. The blast-side loading is characterized by the reflected wave, while the leeward side is comparable to the incident wave and is delayed in time by about 1 to 2 msec. Further refinement of this description is not justified by the current data. Since there are no new experiments being conducted at Albuquerque, it would be desirable to make more EITACC CFD calculations in the future.

This subtask is complete.

Subtask 2.2 Multi-dimensional thorax/lung model. Previous Finite Element Modeling (FEM) of the thorax/lung has modeled both the chest wall and the lung with elements, which led to aphysical solutions because of the large density difference between the chest wall and the lung parenchyma. A one-dimensional model was developed that represented the chest wall mass as a single node, resolving the previous problems.

The technique of treating the chest wall, and other solid boundaries of the lung, as part of the nodes has been implemented in a two-dimensional FEM. The resulting solutions are well behaved and agree with the localized one-dimensional results.

We have ordered and received an anatomical model of the sheep lung to provide specific guidance for refinement of the FEM. Based on that model, a new FEM grid has been selected that better resolves the stresses at the pleural surface and whose elements have an initial shape with less distortion. Both of these changes enhance the calculational accuracy. Further refinements of the chest wall treatment are being implemented to allow proper description of the rigid nature of the thoracic cage, without compromising the tangential motion of the pleural sac.

Task 3. Validation against the pathology database

Subtask 3.1 Generalization of parenchymal work correlate. Work on this subtask has not begun.

Subtask 3.2 Validation of overall injury characterization. Work has begun to validate the INJURY code against the overall injury scores in the pathology database. The first step is to modify the program to read the pressure data in .JIF format, the new standard for exchanging data between the software modules. In the process of making this change, it was clear we needed to rearrange the functional aspects of the program to allow ready access to the model parameters and to provide better output formats for analyzing the data.

The numerical solution algorithm was re-examined. It was discovered that the 5th order Runge-Kutta method, which is ideal for most differential equations, is ill-suited to the sharply peaked pressure traces associated with blast waves. We experimented with an exact analytical solution method, but in the end found that a fully-implicit, time-averaged scheme was not only just as accurate, but was more easily implemented. The code now computes the injury models in a fraction of the previous time (for the same accuracy).

We have begun to link the pathology and blast databases. The INJURY program requires a pressure-time history to make a calculation of the body dynamics. By linking the databases we are linking the observed injury with the measured pressure record. A single unified database is beyond the scope of the current effort, because major reorganization of the VU file format would be required. Instead, we will create separate .JIF files for each shot that can be used with INJURY.

Subtask 3.3 Validation against pathology distribution data. Work on this subtask has not begun.

Subtask 3.4 Model refinement. Work on this subtask has not yet begun.

Task 4. Development of a human thorax/lung model

Subtask 4.1 FEM human thorax/lung model. Work on this subtask has not yet begun.

Subtask 4.2 Modified injury predictions. Work on this subtask has not yet begun.

Subtask 4.3 Human model into INJURY software. Work on this subtask has not yet begun.

Task 5. Extension of Pathology Database to GI Injury

Subtask 5.1 Data Entry. The database was extended to include fields for the gastrointestinal tract. All of the available Albuquerque text data has been entered.

This subtask is complete.

Subtask 5.2 Correlation of Injury. Work has begun to correlate the gastrointestinal injury with blast wave parameters. Preliminary results will be passed to the Defense Nuclear Agency as soon as possible.

Subtask 5.3 Reporting and Distribution. Work is not planned until next year.

Research Topic 2: Critical Parameters in Complex Waves

Task 1. Complete Description of Complex Waves

Subtask 1.1 Compilation of load data in enclosures. A review of the available load data for blasts within enclosures has been performed. The only data sufficiently detailed to serve the purposes of injury modeling is that collected at the Albuquerque Test Site for WRAIR. The Navy charge/volume scaling rules are more applicable to the static overpressure in unvented spaces. The information pertinent to the use of this data for load determination has been entered into the blast database and, where possible, the traces have been digitized for future analysis.

This subtask has been completed.

Subtask 1.2 CFD calculations. JAYCOR's EITACC computer program has been applied to the simulation of single charge explosions within an enclosure. The results have been compared with the measurements from the Albuquerque Test Site to determine the range of validity of the model and with the method of images computer program COMPLX. The results show that CFD methods can be used to predict much of the detail of the complex waves and to provide an analytical source of data for loading that can be used in injury prediction models. The details of this investigation have been described in a draft technical report delivered in January, 1990.

This work will eventually be incorporated into a single report on complex waves that includes the results of Task 2.

This subtask has been completed.

Subtask 1.3 Critical parameters of blast. Work has not begun on this subtask.

The CFD calculations can be quite time consuming. During the coming quarter, JAYCOR is taking delivery on new, high-speed workstations that are almost a factor of ten faster than our current workstations. We plan to defer this subtask (and subtask 1.4) until the following quarter, when the hardware will be fully operational and the calculations can be made more cost effectively. The delay will also allow us more time to analyze the existing data and the predictions of the COMPLX code.

Subtask 1.4 Load distribution for complex waves.

Work has not begun on this subtask. See previous subtask.

Task 2. Incorporate findings into COMPLX

Subtask 2.1 Extend the COMPLX model. Work has begun to analyze the predictions of the COMPLX code. Several areas of improvement have been identified. First, the current algorithm for determining the intersection of a blast ray with a reflecting surface was found to be sensitive to numerical precision. A new algorithm has been derived and is being tested. Second, the previous algorithm terminated the image-generating cycle after a fix number of reflections. Further analysis revealed that many higher-order reflections are important to the pressure signal in the 10 to 20 msec. time frame. It appears that part of the discrepancy with data, that had earlier been attributed to pressurization effects, are actually explained by multiple reflections.

Subtask 2.2 Validation against CFD model. Work has begun to compare the COMPLX calculations with the EITACC CFD calculations. The agreement is qualitatively good, but there are clearly features that only the CFD calculations can capture. The investigation will focus on the physical origin of those differences and whether they can be incorporated into the BWAVES code.

Task 3. Critical parameters of injury

Subtask 3.1 Evaluate multi-dimensional aspect of injury.

Subtask 3.2 Validation of the extended COMPLX injury model.

Subtask 3.3 Determination of critical parameters.

Subtask 3.4 Upgrade INJURY software.

Work on this Task has not begun.

MODELING OF THE NON-AUDITORY EFFECTS OF BLAST

Mid Term Briefing

James H. Stuhmiller, Ph.D. - Principal Investigator
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Presented To
U. S. Army Medical R&D Command
Ft. Detrick, MD

August 16, 1990

BASIS OF CURRENT ARMY DOCTRINE

Bowen correlate:	$P_B = P_S/[1 + 6.76/Ta^{1.064}]$
LD50 (side-on, free-field):	$P_B = 2.52 \pm 1.23$ atm
Incidence of lethality	$= (P_B)^{power}$
Incidence of "combat ineffectiveness:	$=$ (Incidence of lethality)^{power}
Threshold lung injury (side-on, free-field):	$P_B = 0.68$ atm
Threshold eardrum rupture:	$P_S = 0.34$ atm
Non-auditory limit (Mil Std 1474B at 5 msec)	$P_S = 0.34$ atm

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PROBLEMS

No guidance on organ-specific effects

[Some systems are more vulnerable]

No guidance on pathology effects

[Severity, location, incidence]

No guidance on consequences

[Physiological effects, performance]

No guidance on application to complex waves

[P_B does not correlate]

PRINCIPAL USAMRDC EXTRAMURAL ACTIVITIES

Field testing at Albuquerque

- Duration: about 10 years for USAMRDC
- Approach: specific observations of specific conditions
- Findings: "real," but isolated
- Products: reports, unaccessible data

Bioengineering modeling at JAYCOR

- Duration: about 10 years for USAMRDC
- Approach: systematic investigation of fundamental processes
- Findings: general, but unvalidated
- Products: reports, user-oriented software

GOALS OF CURRENT CONTRACT

Task 1. "Lung Pathology"

Organize Albuquerque data into a usable form

Quantify trends

Validate biomechanical models

Task 2. "Complex Waves"

Characterize blast field

Assess the capability to predict

Identify what is important

Improve injury prediction

Task 3. "Combined Injury" (DNA)

Extend pathology database to GI

Evaluate importance of blast on battlefield

Estimate the medical and performance consequences

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Task 1. Lung Pathology
ORGANIZE ALBQ DATA INTO USABLE FORM

Compilation of Data
- Cross check all references (logbooks, data, reports)
- Color Xerox all materials
- Separate file for each animal (about 700)
- Cross-index all pictures
- **Product: reorganized hardcopy of all pathology data**

Pathology Database Structure
- **Product: reorganized, expanded pathology worksheets**

Software Development
- **Product: User-oriented software for future data entry**

Data Entry
- **Product: Electronic form of database**

Data Qualification
- Blast parameters
- Pathology re-grading
- **Product: Extension of Baker's relations for Mach region**

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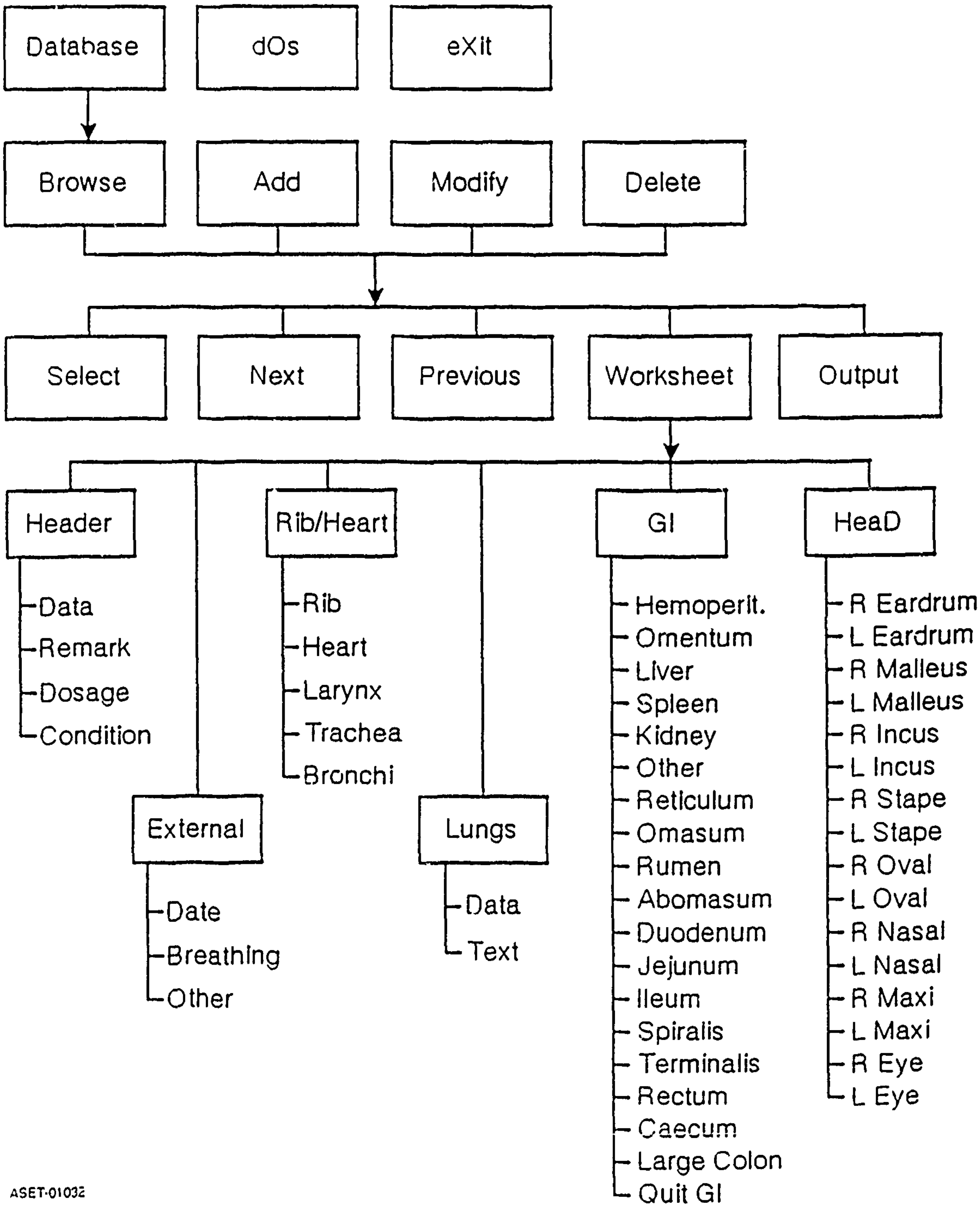
PATHOS MENUS



JAYCOR PATHO Database Browse Select

Select Next Previous Worksheet Output Quit

Select Subject

Selection Criteria

All

Specific subject

Range of subjects

Project

JAYCOR PATHO Database · Browse Worksheet

Header External Rib/Heart Lungs GI heaD Quit

External Breathing Other Quit

Character of Breathing

External Data ID:

T.O.D.
KIA
Singe
Wounds
Corneal
Ear-Pinch
Inter-Dig
Stand
Nose
Heart
Respir

Other Text

External

JAYCOR   PATHO Database   Browse   Worksheet

Header   External   Rib/Heart   Lungs   GI   heaD   Quit

Rib   Heart   Larynx   Trachea   Bronchi   Quit

Rib Data   ID: 00002A

RR Frac   neg.
LR Frac   neg.
R Inter   neg.
L Inter   neg.

Heart Data   ID: 00002A

Embol   neg.
Contus   neg.
Epi   neg.
Endo   neg.

Larynx

moderate.

Trachea

Bronchi

??? both sides. ???

Rib Fractures & Heart

DAYCOR PATHO Database Browse Worksheet
Header External Rib/Heart Lungs CI Head Quit
Lung Text Quit

Lung Data	ID: 00002A	
Hemo	neg.	
Pneumo	neg.	
[illegible]	[illegible]	
LL Wt	1.00000	g
Right L	.540000	%
Left L	.390000	%

Lung Text
neg.

Right and Left Lung

JAYCOR   PATHO Database   Browse   Worksheet   GI
Header   External   Rib/Heart   Lungs   GI   Head-   Quit
G.I. Tract

GI Data ID: 00002A

Hemoperitoneum
Omentum
Liver
Spleen
Kidney
Other
Reticulum
Omasum
Rumen
Abomasum
Duodenum
Jejunum
Ileum
Spiralis
Terminalis
Rectum
Caecum
Large Colon
Quit GI

Hemoperitoneum
neg.

JAYCOR   PATHO Database   Browse   Worksheet
Header   External   Rib/Heart   Lungs   GI   Head   Quit
Head   Text   Quit

Head & Sinus Data	ID: 00003
R Eardrum	A
L Eardrum	A
R Malleus	A
L Malleus	A
R Incus	A
L Incus	A
R Stape	A
L Stape	A
R Oval	A
L Oval	A
R Nasal	eg.
L Nasal	eg.
R Maxi	eg.
L Maxi	eg.
R Eye	
L Eye	

Head Text

Head and Sinus area

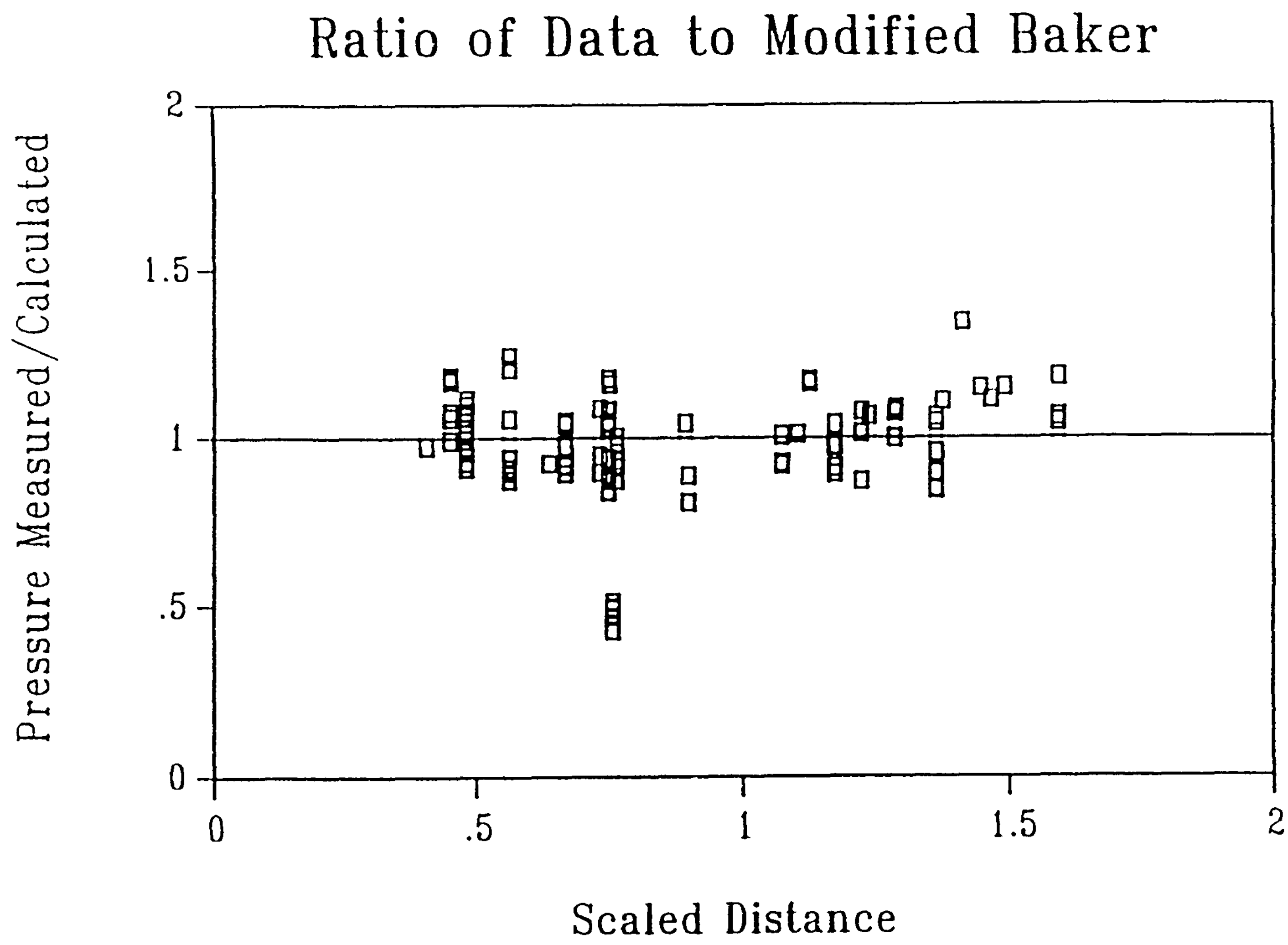


Figure 2. Comparison of measured peak incident pressure with value calculated from a modification of Baker's relations that accounts for wave interaction in the Mach stem.

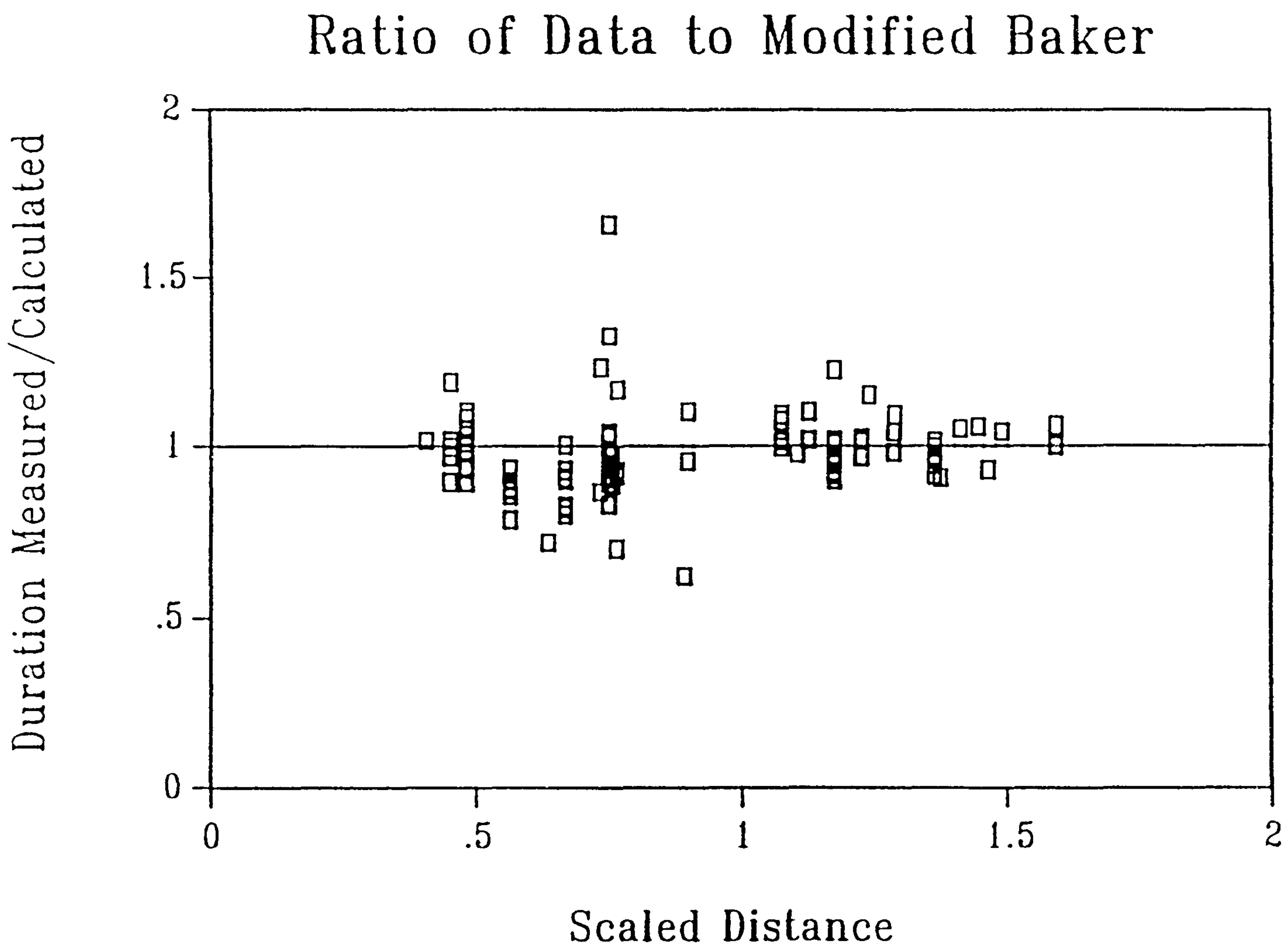


Figure 3. Comparison of measured positive phase duration with values calculated from a modification of Baker's relations.

Task 1. Lung Pathology

QUANTIFY TRENDS

Single exposure, free-field incidence correlation

Blast parameters calculated from modified Baker relation

Overall injury grades for trachea, lung, and GI

Animals sorted into P_B ranges and distribution fit analytically

5% incidence of any injury at $P_B = 0.45$ atm

5% incidence of severe injury at $P_B = 0.61$ atm (Trachea); 0.72 atm (Lung); 0.83 atm (GI)

Products: **Quick-Look Report**
Statistical analysis in INJURY

JAYCOR

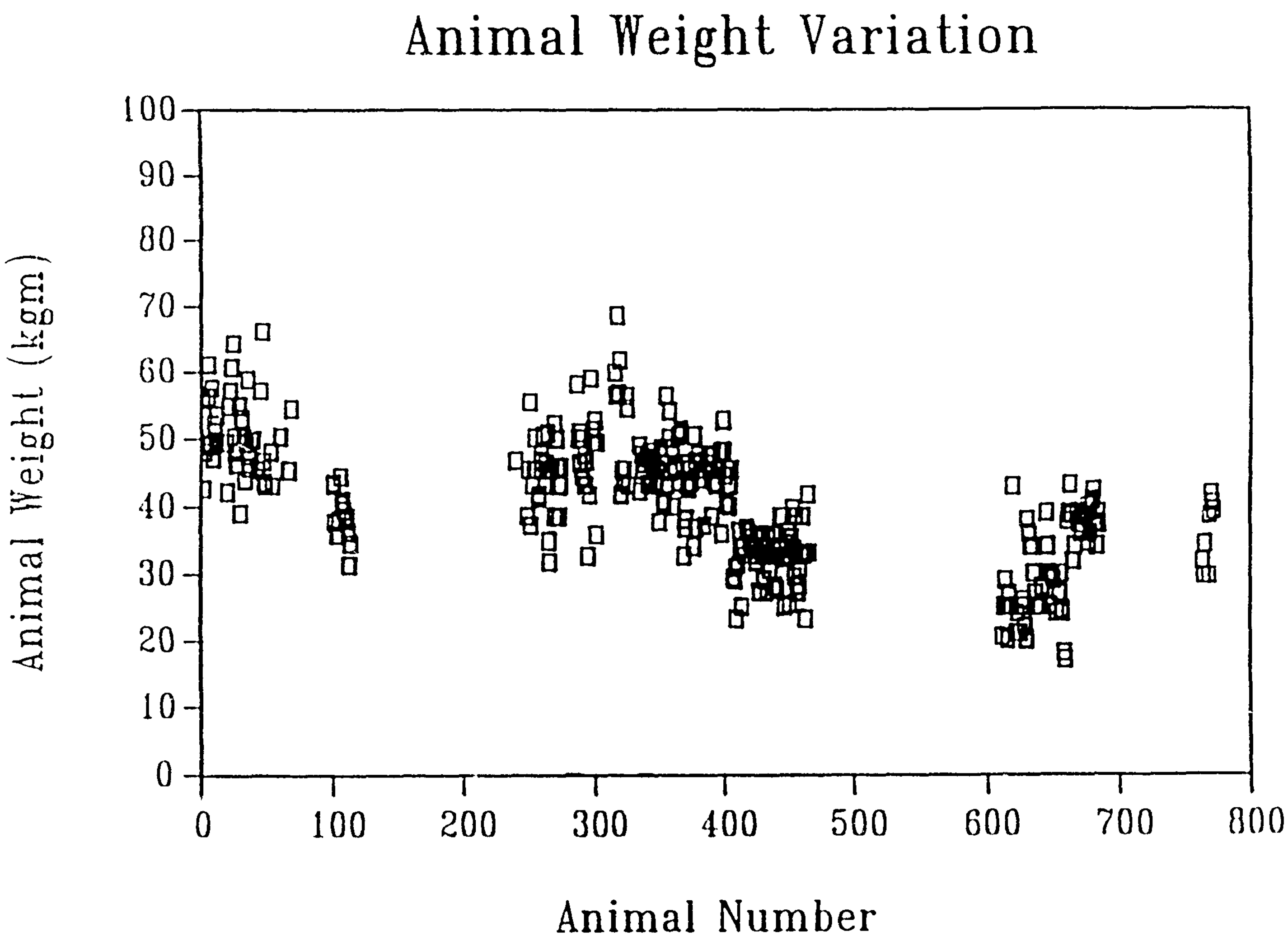


Figure 1. Variation of animal weight with animal number . Gaps represent animals not used in subset. Since animal numbers are assigned sequentially, a decrease in weight in later tests can be seen.

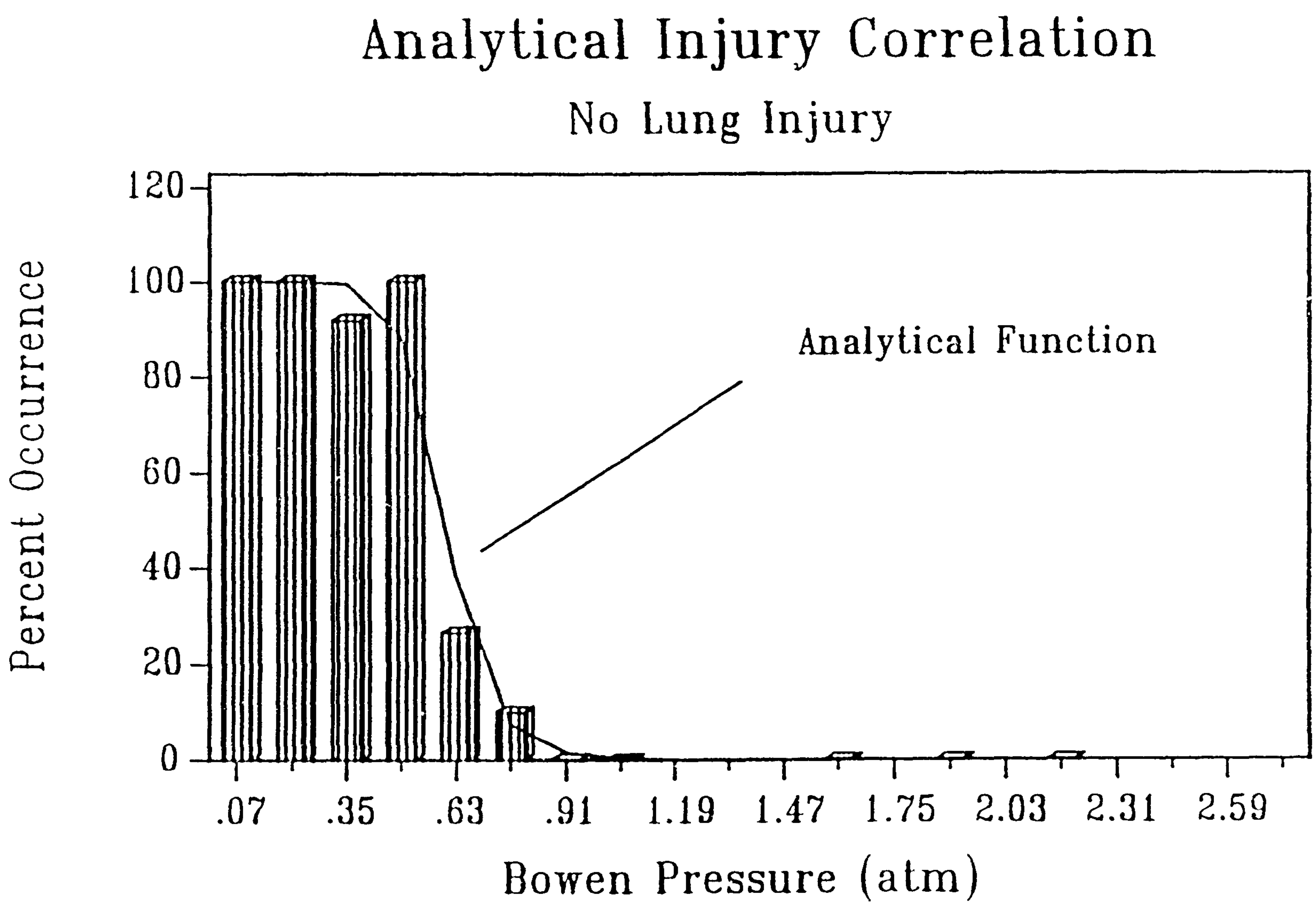


Figure 5a. Comparison of observed occurrence of no lung injury with analytical function.

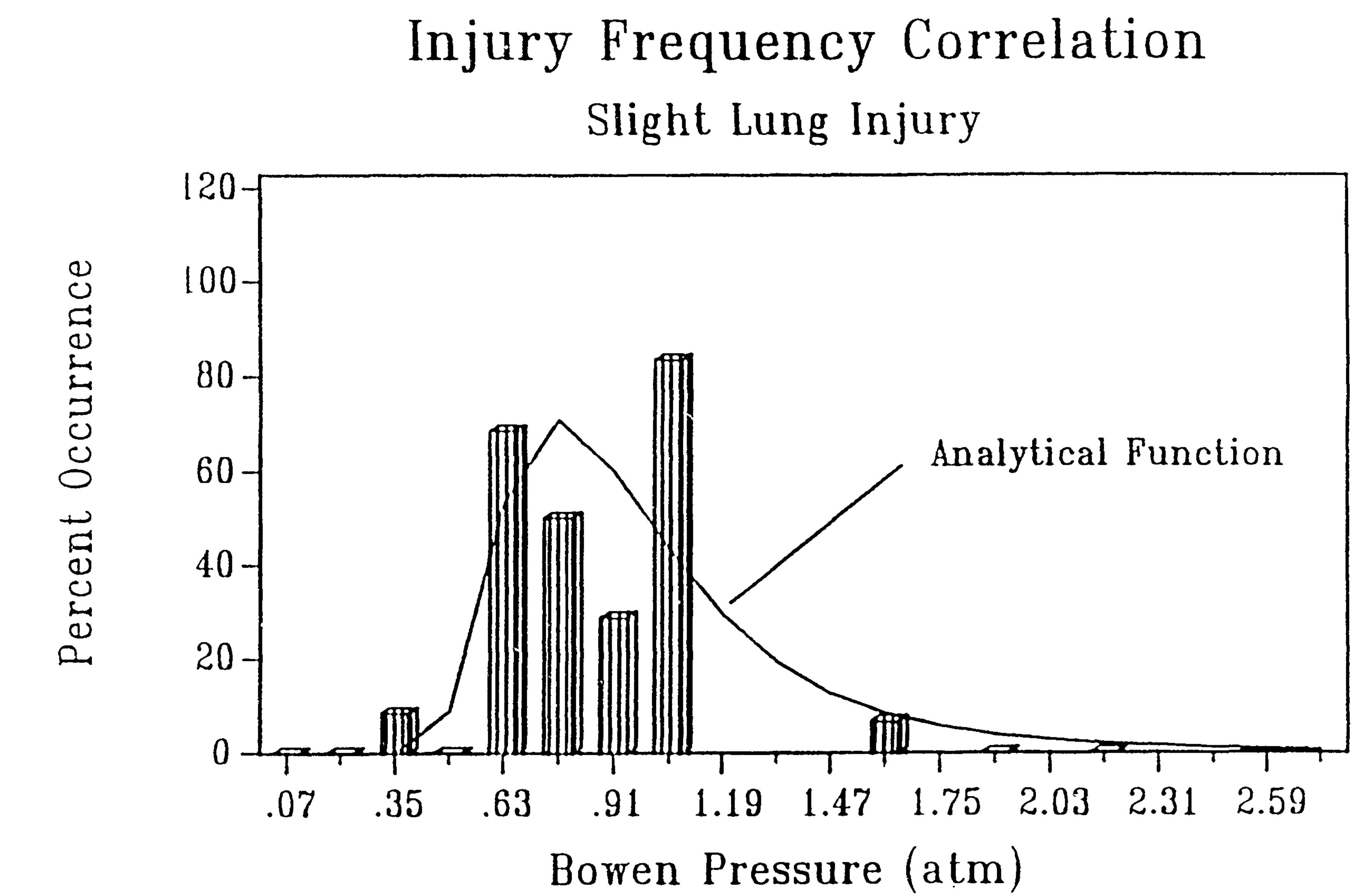


Figure 5b. Comparison of observed occurrence of slight lung injury with analytical fuction.

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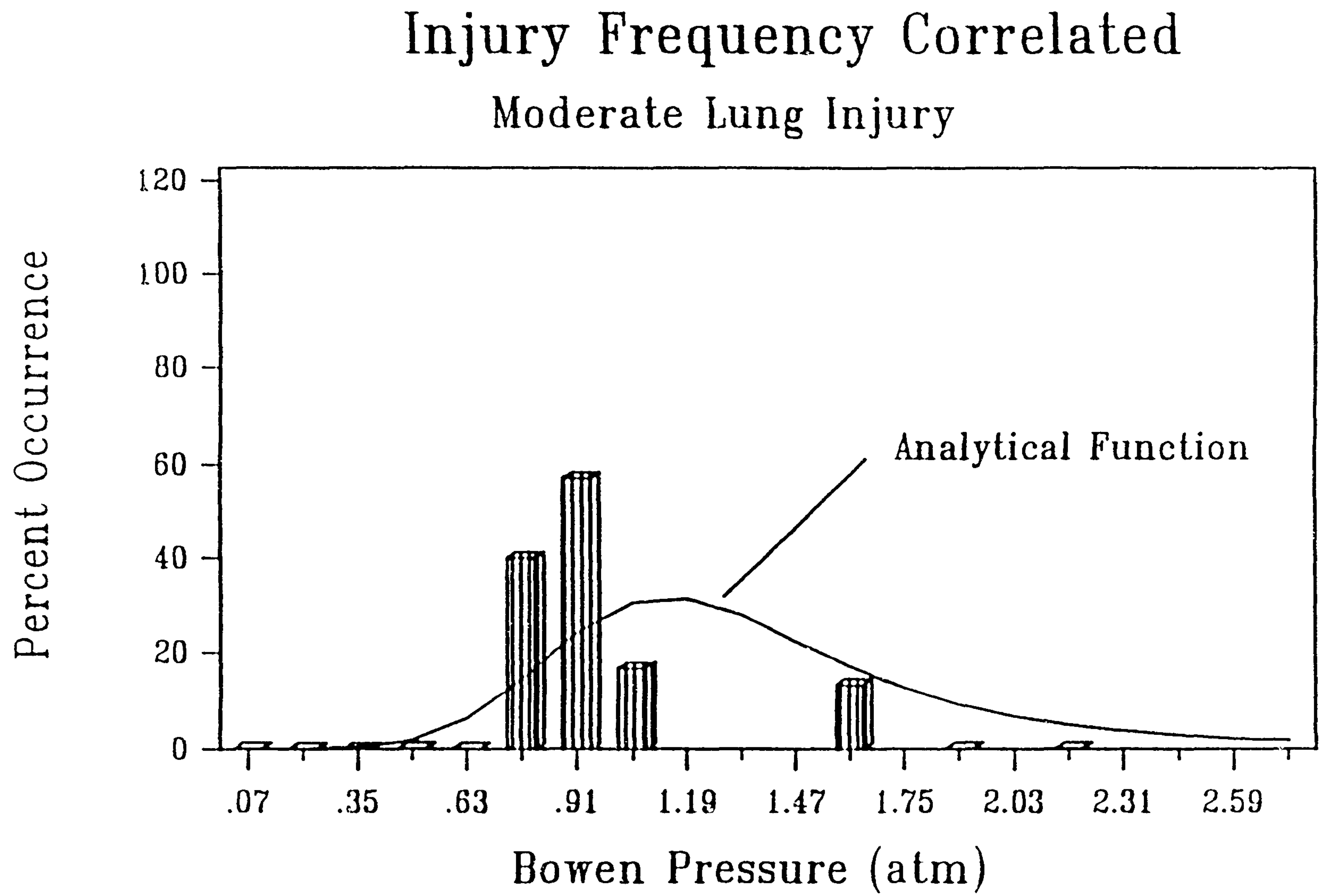


Figure 5c. Comparison of observed occurrence of moderate lung injury with anlaytical function.

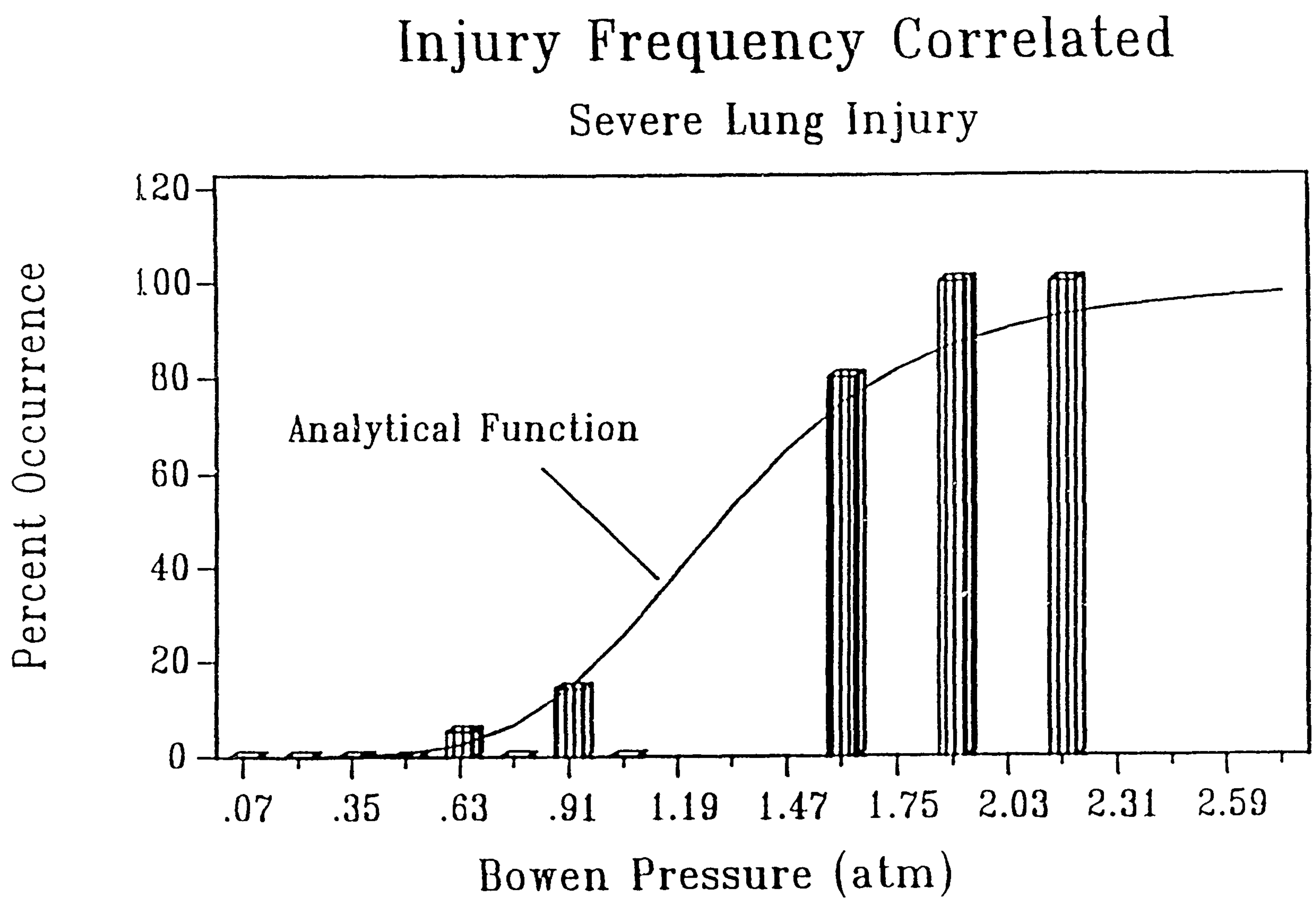


Figure 5d. Comparison of observed occurrence of severe lung injury with analytical function.

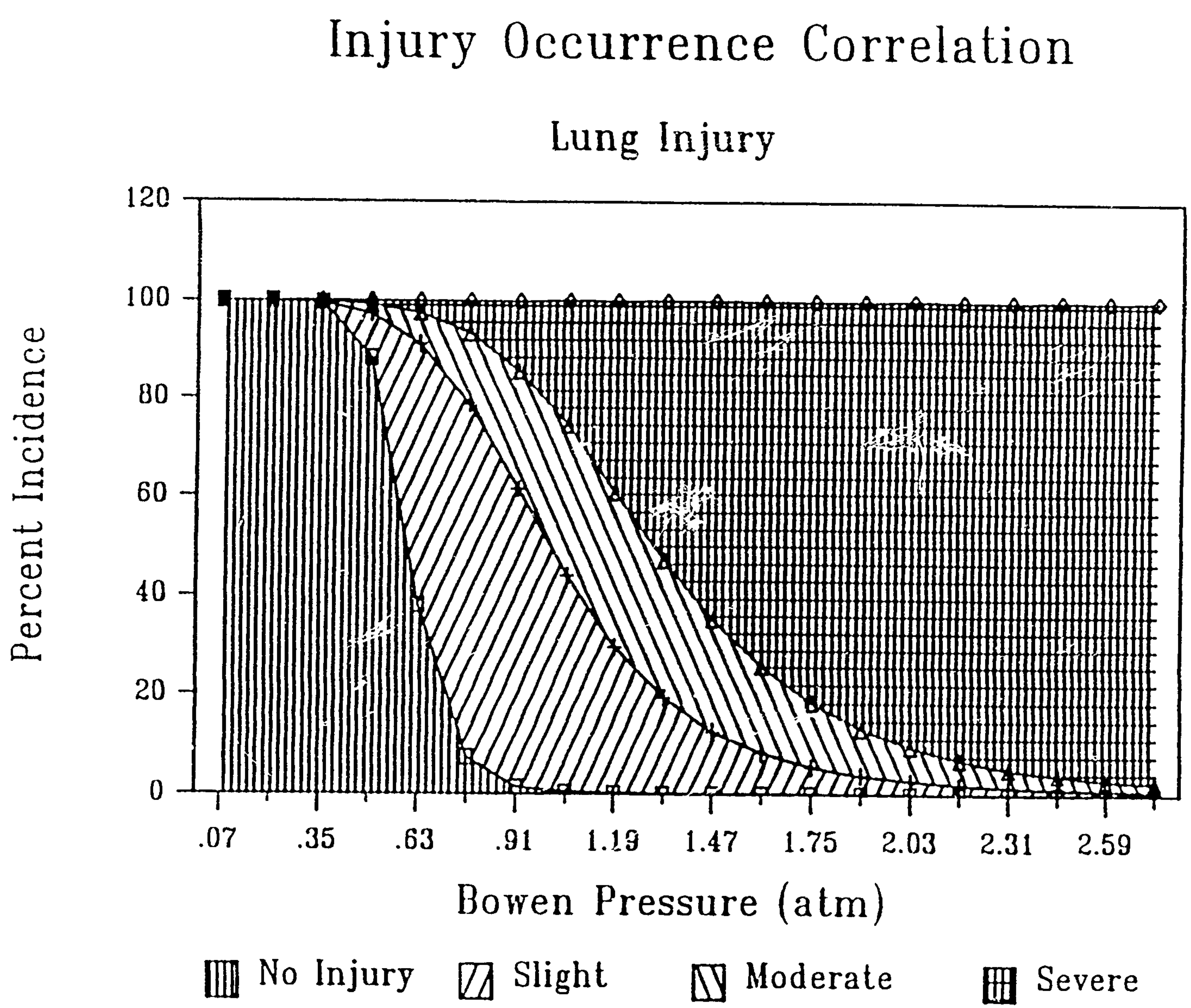


Figure 5e. Percent incidence of lung injury as a function of the Bowen Pressure as correlated with analytical functions.

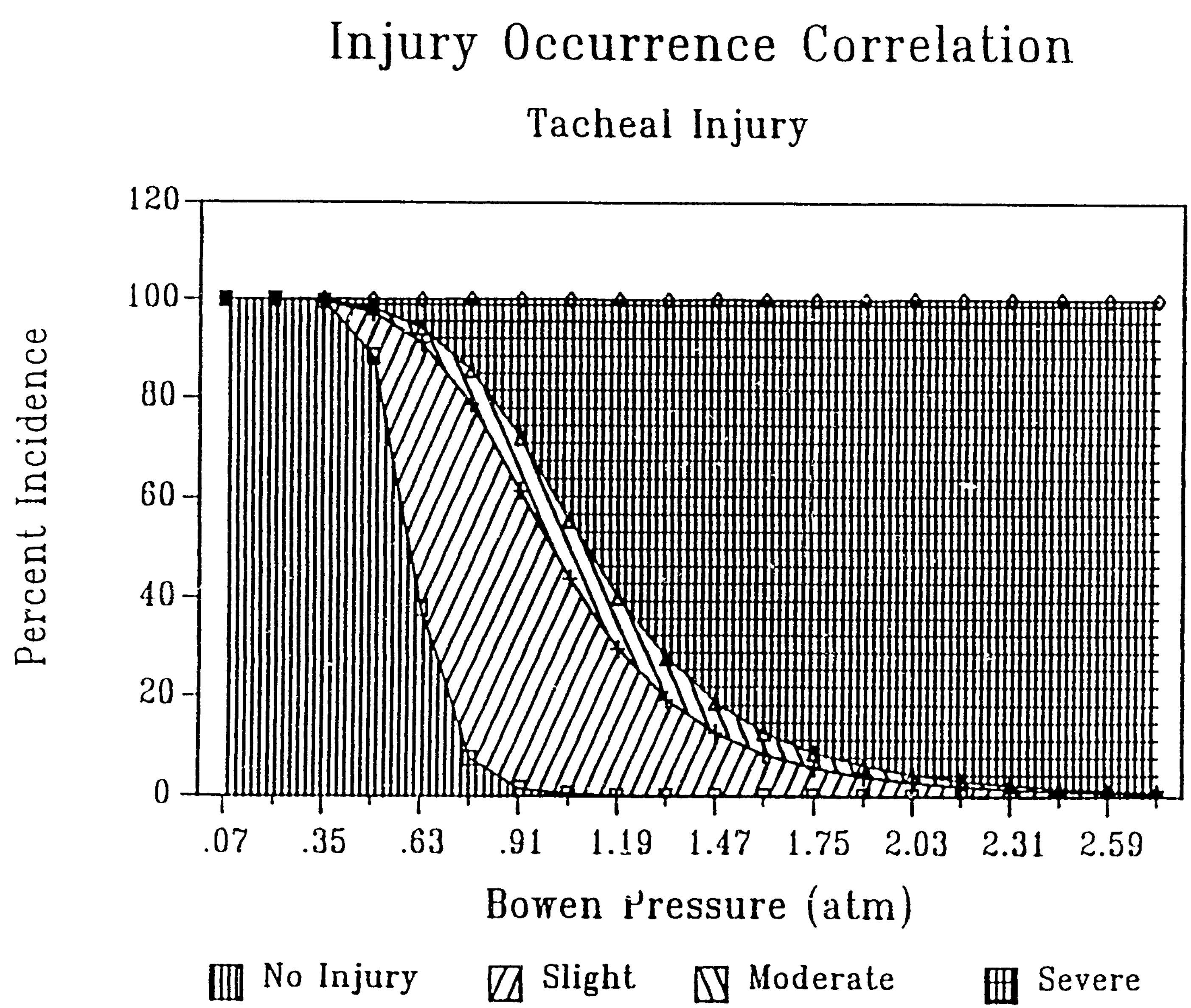


Figure 4e. Percent incidence of tracheal injury as a function of the Bowen pressure as correlated with analytic functions.

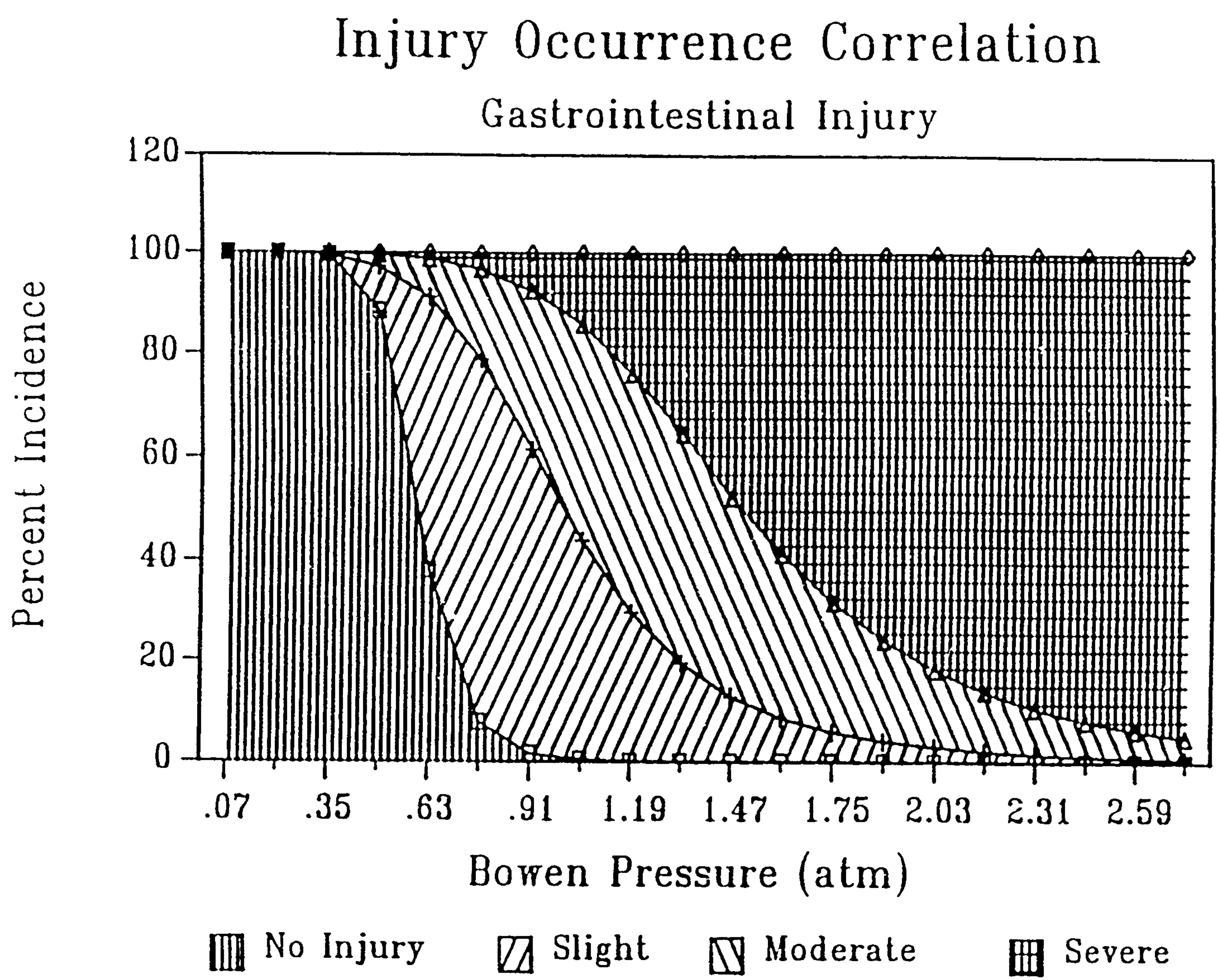
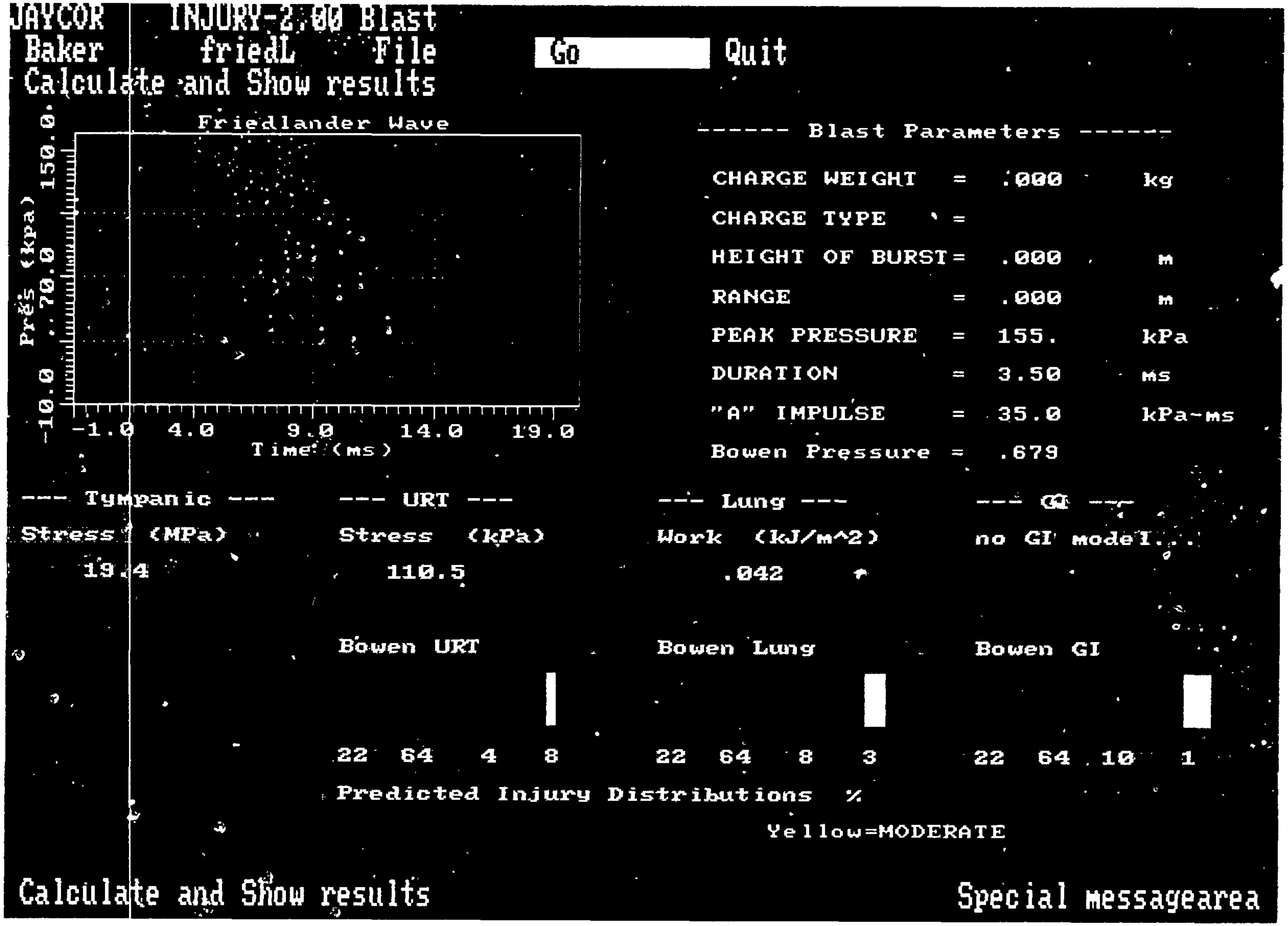


Figure 6e. Percent incidence of gastrointestinal injury as a function of Bowen pressure as correlated with analytical functions



JAYCOR
INJURY-2.00 Blast
Baker
friedL
File
Calculate and Show results
Go
Quit
Friedlander Wave
Pres (kpa)
150.0
70.0
-10.0
-1.0
4.0
9.0
14.0
19.0
Time (ms)
------ Blast Parameters ------
CHARGE WEIGHT = .000 kg
CHARGE TYPE =
HEIGHT OF BURST = .000 m
RANGE = .000 m
PEAK PRESSURE = 155. kPa
DURATION = 3.50 ms
"A" IMPULSE = 35.0 kPa-ms
Bowen Pressure = .679
--- Tympanic ---
Stress (MPa)
19.4
--- URT ---
Stress (kPa)
110.5
--- Lung ---
Work (kJ/m^2)
.042
--- GI ---
no GI model...
Bowen URT
Bowen Lung
Bowen GI
22 64 4 8
22 64 8 3
22 64 10 1
Predicted Injury Distributions %
Yellow=MODERATE
Calculate and Show results
Special messagearea

Task 1. Lung Pathology

VALIDATE BIOMECHANICAL MODELS

Extended Finite Element Model

Multi-dimensional

Rigid chest wall displacement

Slip between pleural sac and wall

Improved Data Comparisons

Products: **ADINA® model, report**

Work correlate extension, new INJURY

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Task 2. Complex Waves

CHARACTERIZE BLAST FIELD

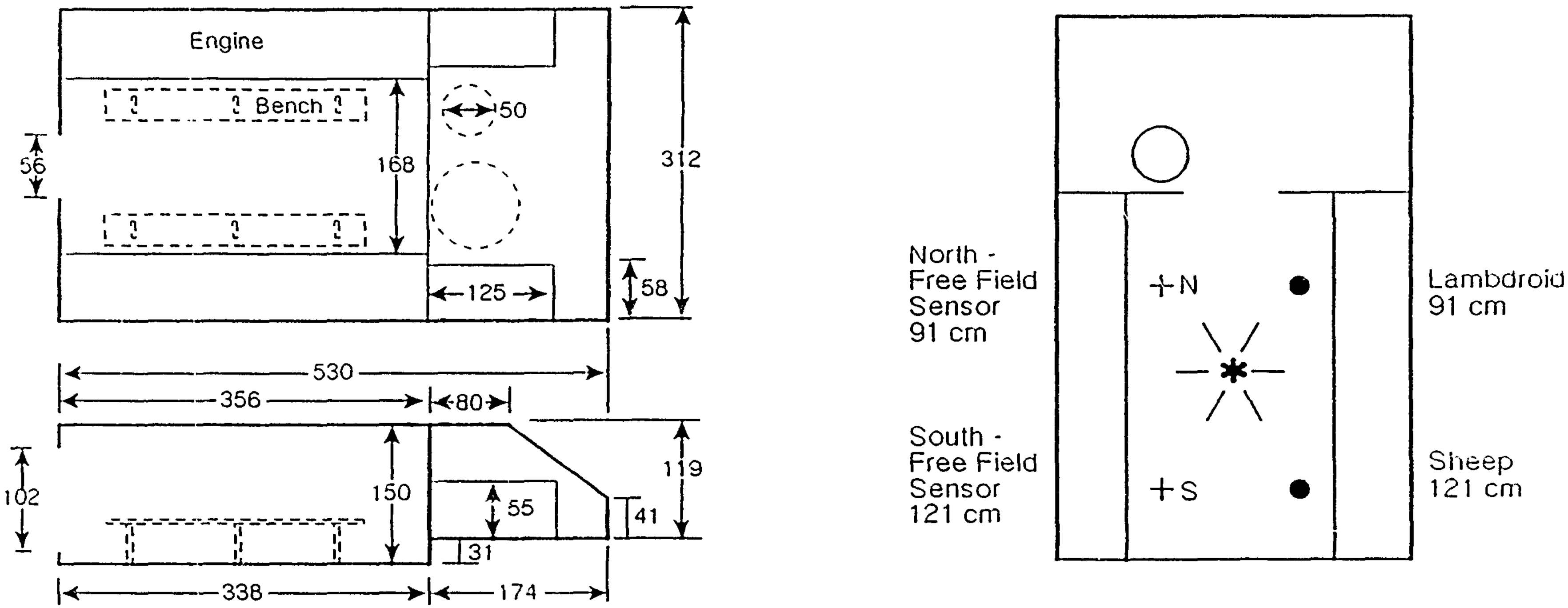

Figure 4-1. APC specification and sensor location.

Task 2. Complex Waves

PREDICTION METHODOLOGIES

EITACC

- Computational solution to Navier-Stokes equations
- Complex geometries
- Valid over a wide range of phenomena
- Long running (workstation)

COMPLX

- Method of images to treat wall reflections
- Baker's relations for blast propagation
- Sensor response function
- Heuristic venting treatment
- Quick running (PC)

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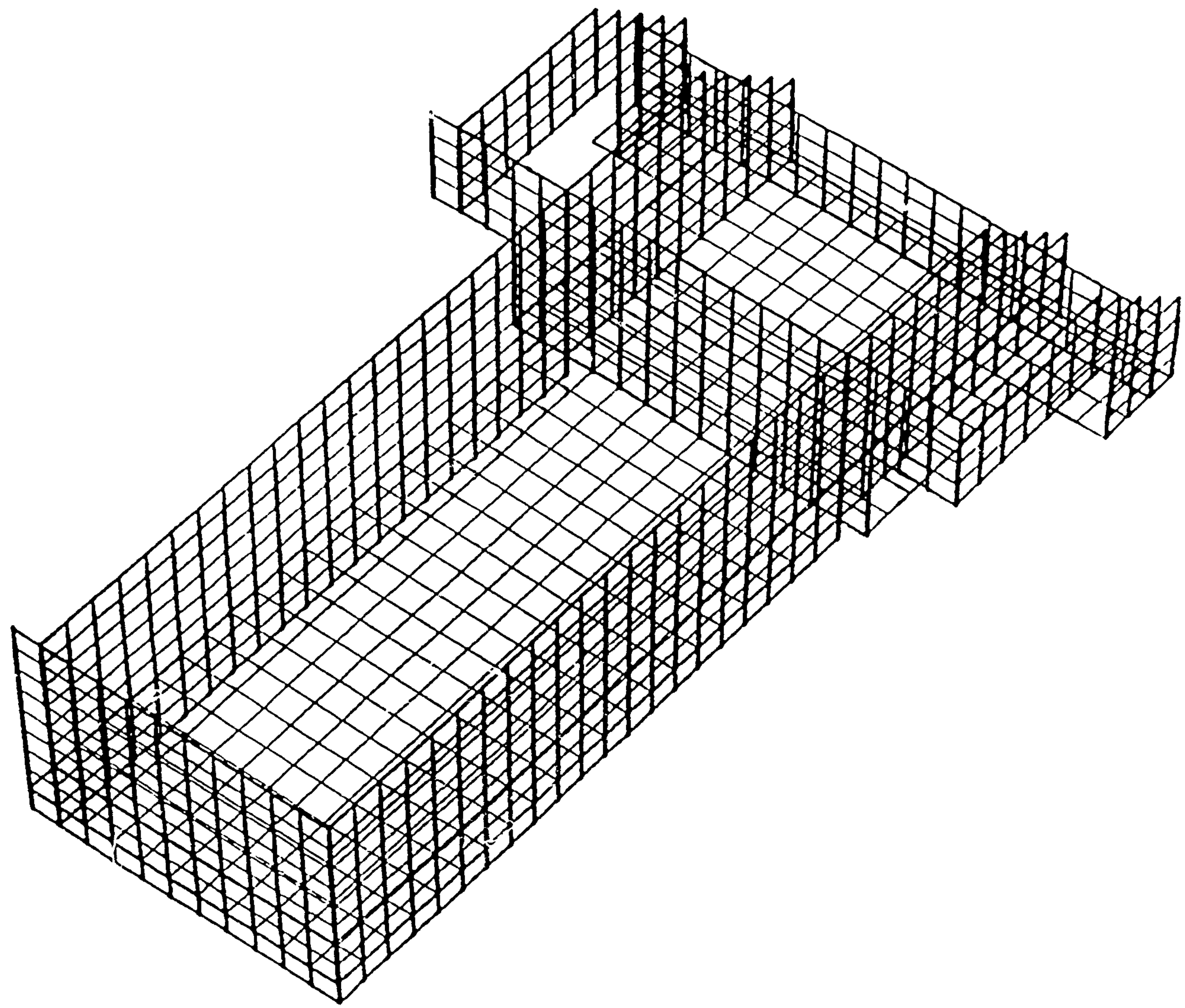


Figure 4-2. Compu.-tional cell network for calculating the blast in an APC.

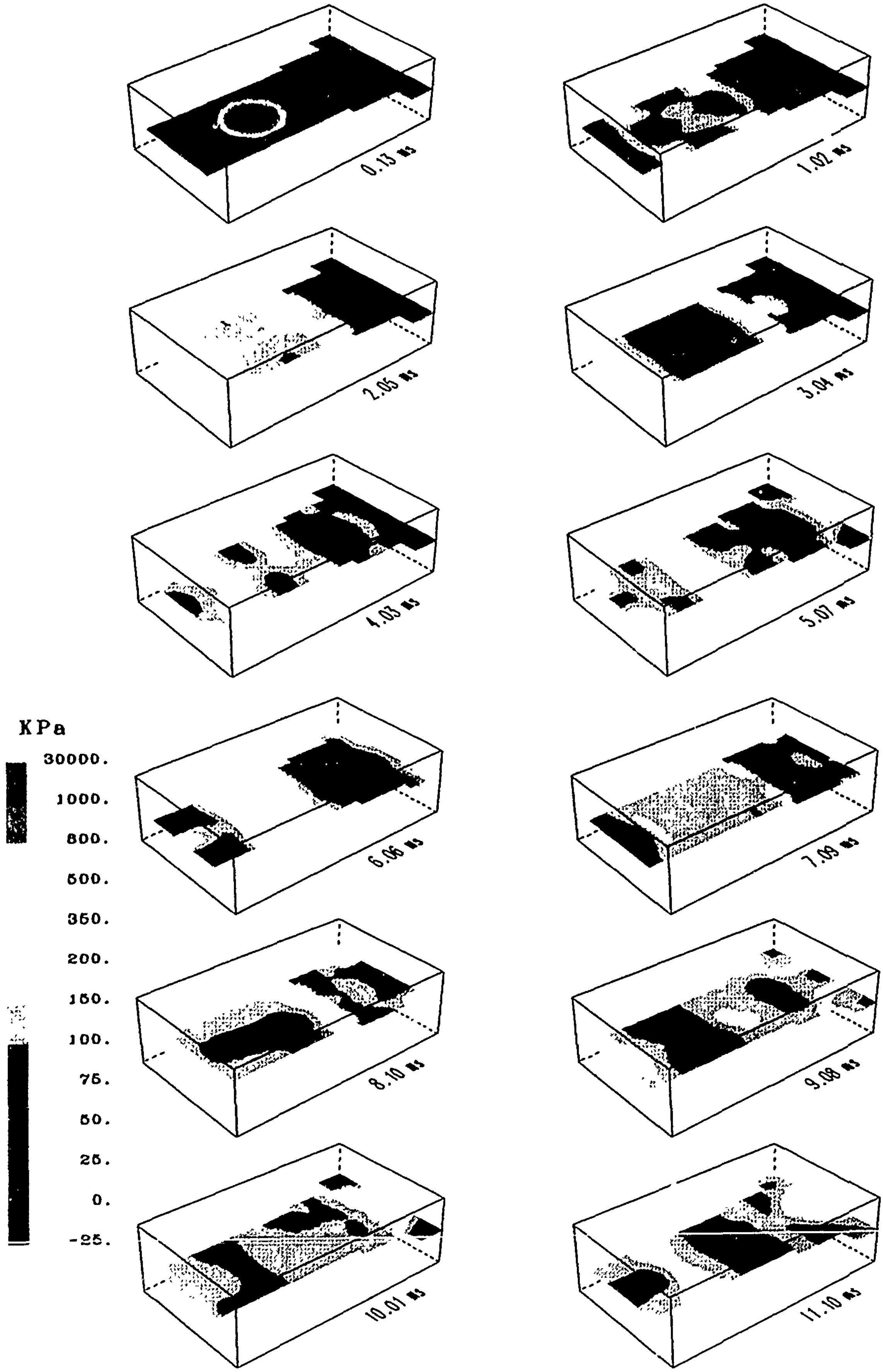
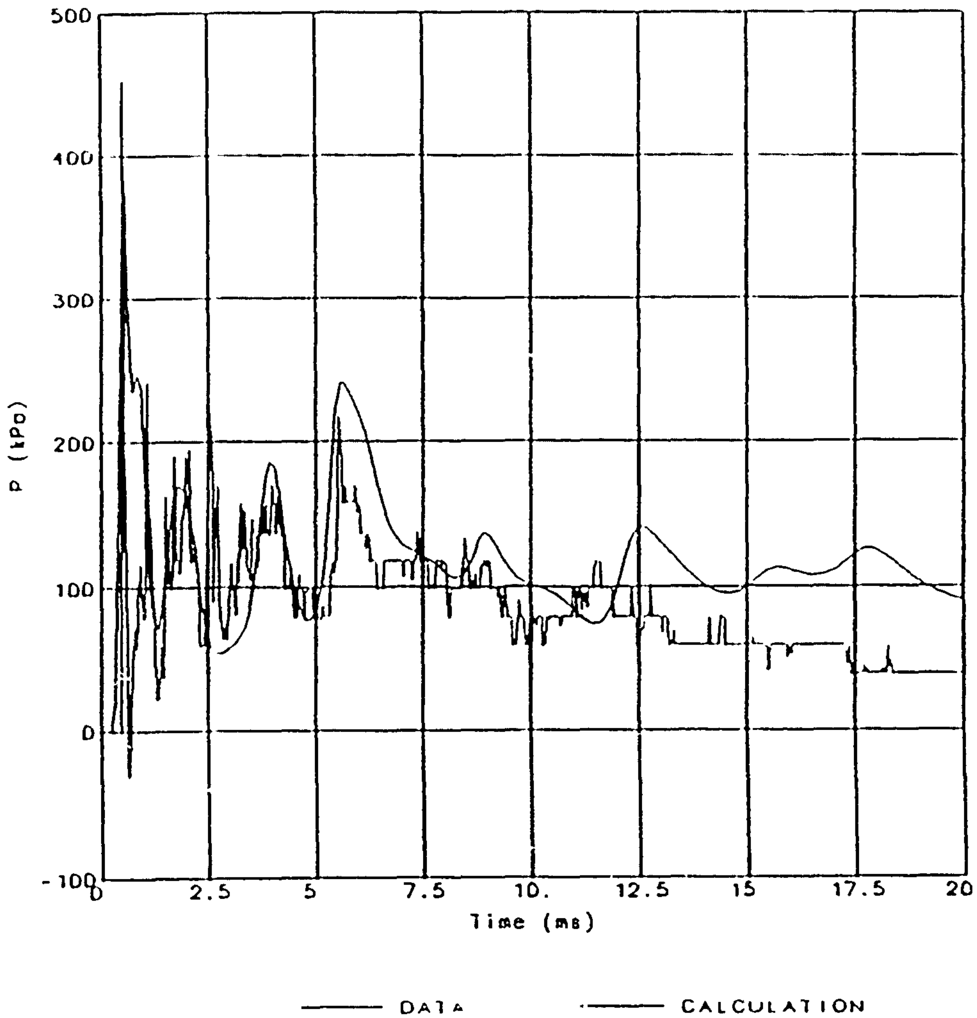
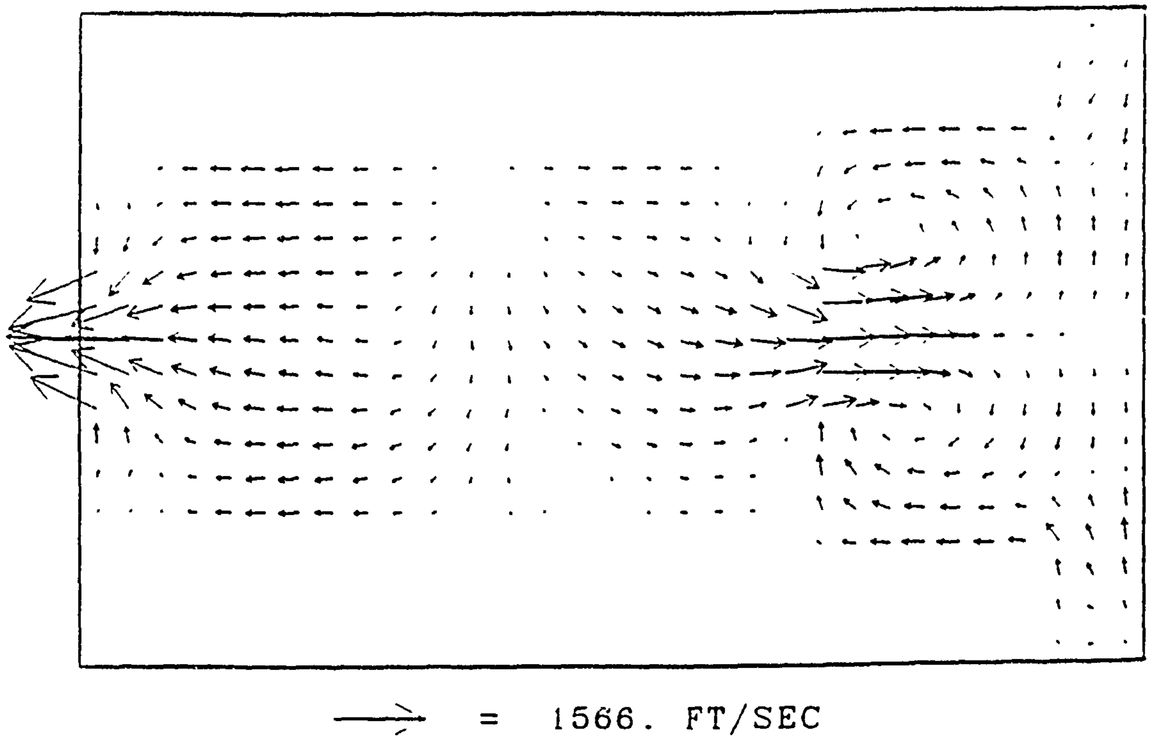


Figure 4-3. Pressure history from a blast of 1 lb C-4 in an APC.

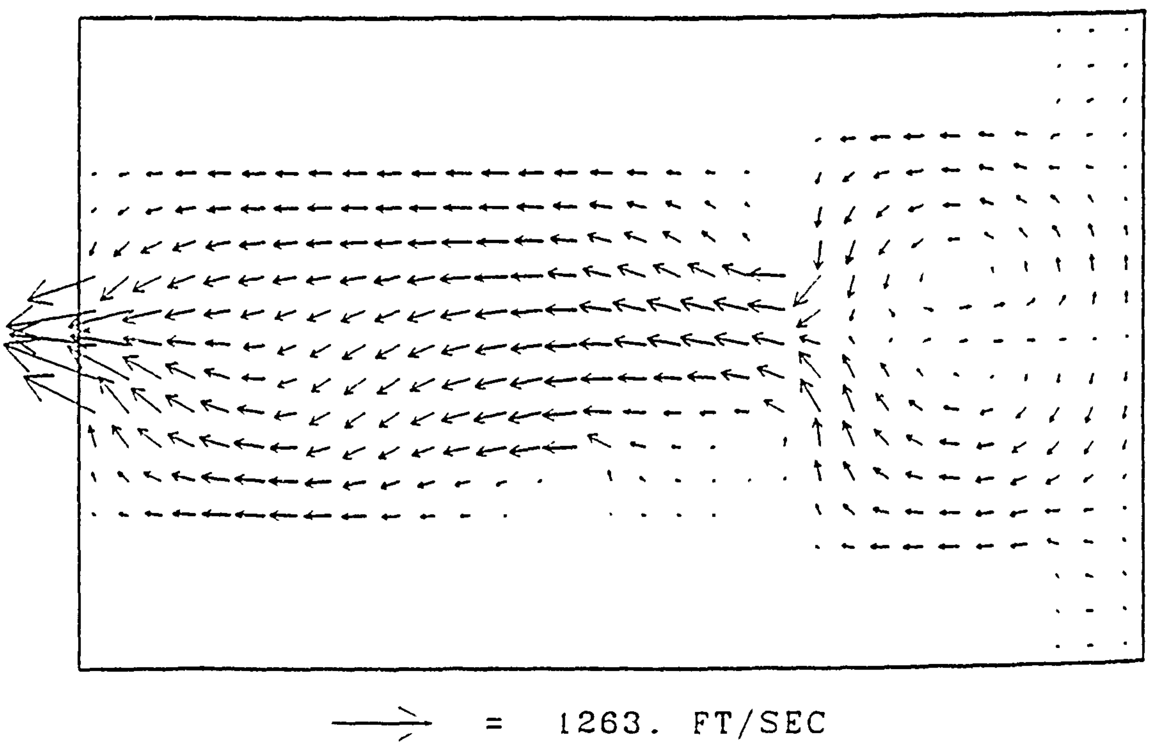


(a) North free field sensor, 36 in. range, 30 in. height

Figure 4-5. Comparison between calculated and measured pressure histories from a blast of 1 lb of C-4 in an APC.

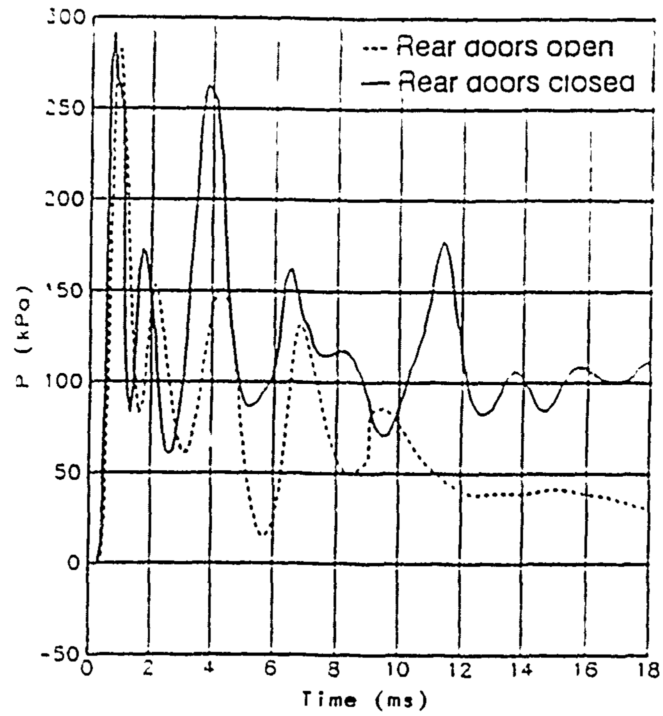


(a) 9 ms

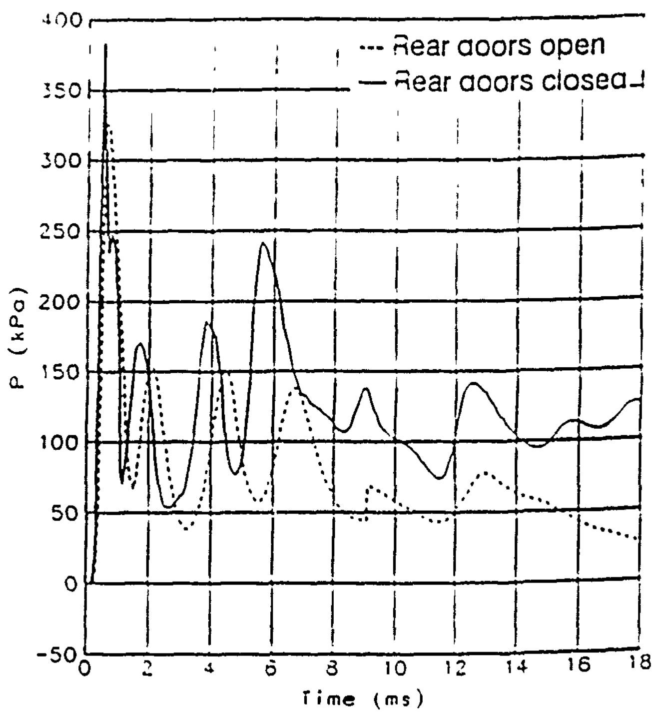


(b) 18 ms

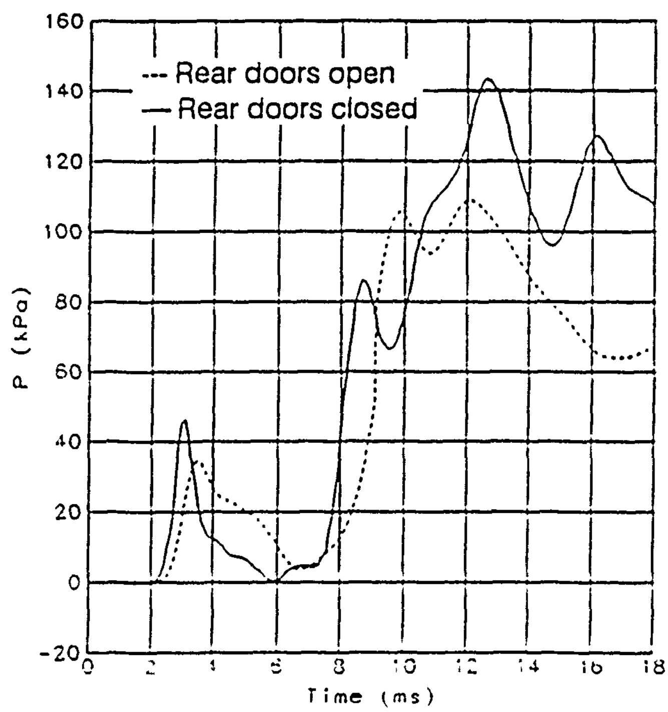
Figure 5-3. Velocity vectors in a horizontal plane at the center of the APC.



(a) At location of south free field sensor



(b) At location of north free field sensor



(c) In crew compartment

Figure 5-1. Pressure time history from a blast of 1 lb of C-4 in an APC.

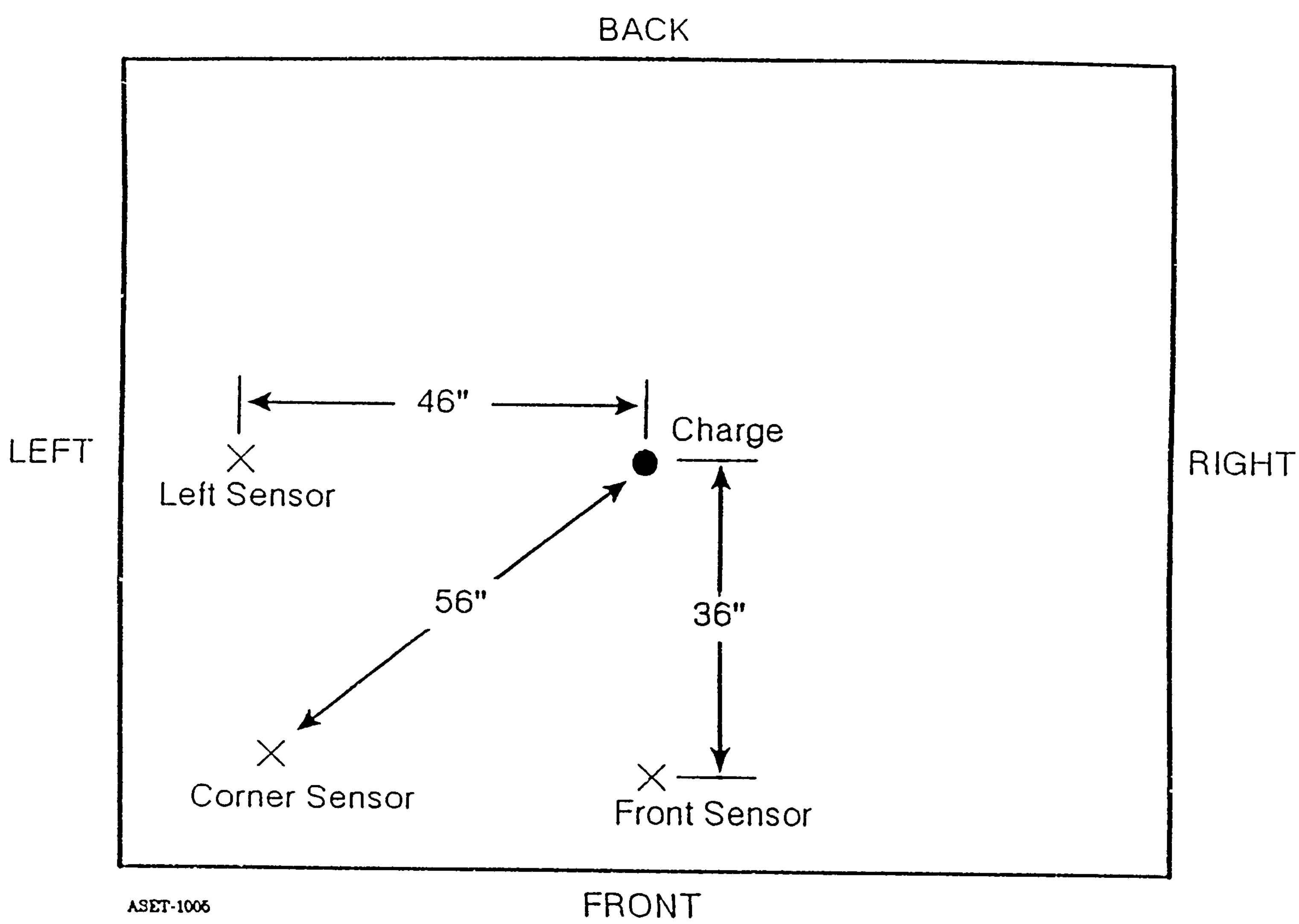
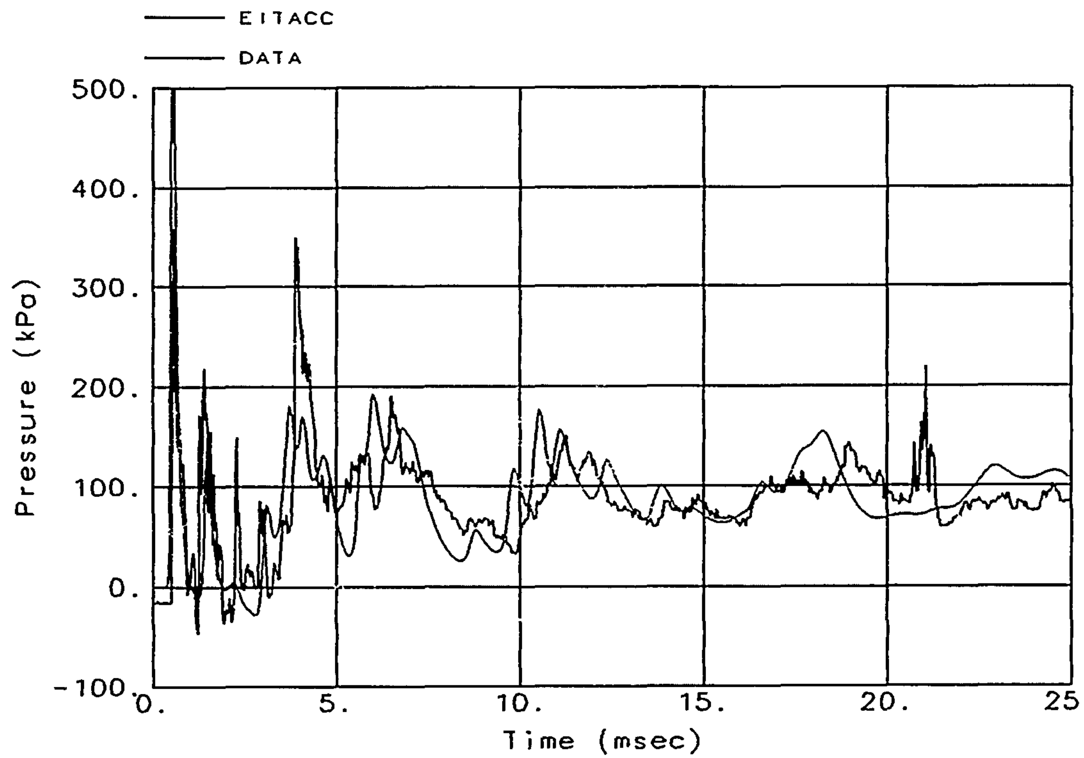
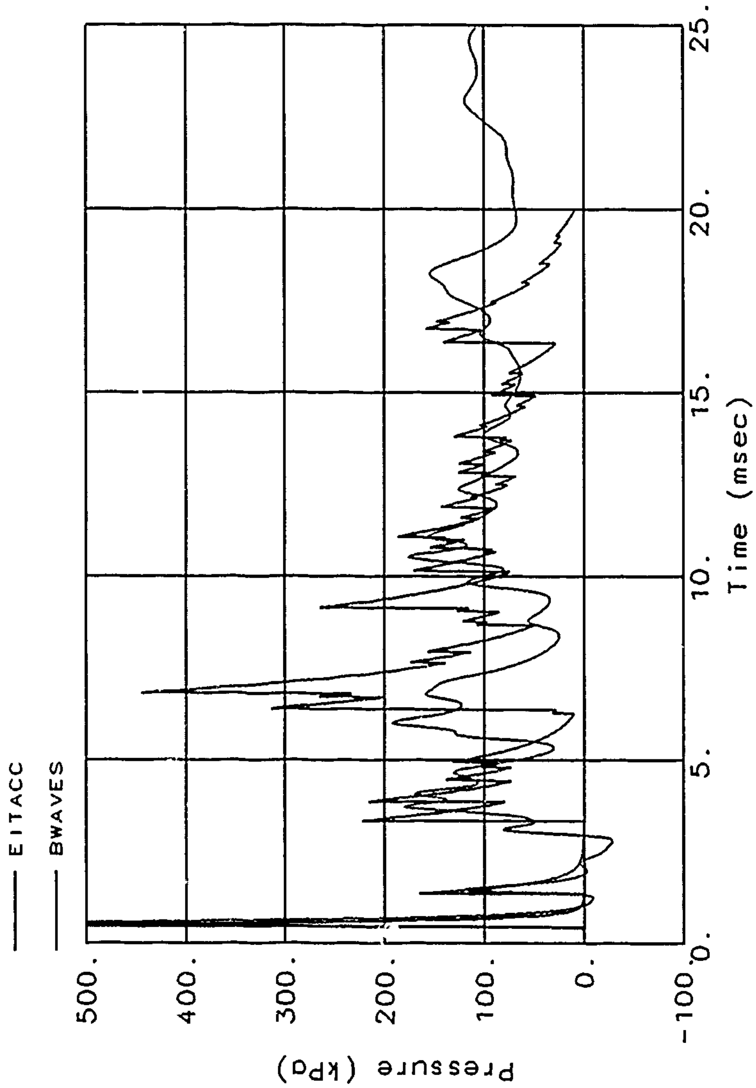


Figure 8-1. Definition of free field sensor locations in the field bunker.

eida.grf



EITACC
DATA
500.
400.
300.
200.
100.
0.
-100.
Pressure (kPa)
0.
5.
10.
15.
20.
25.
Time (msec)



eibw.grf

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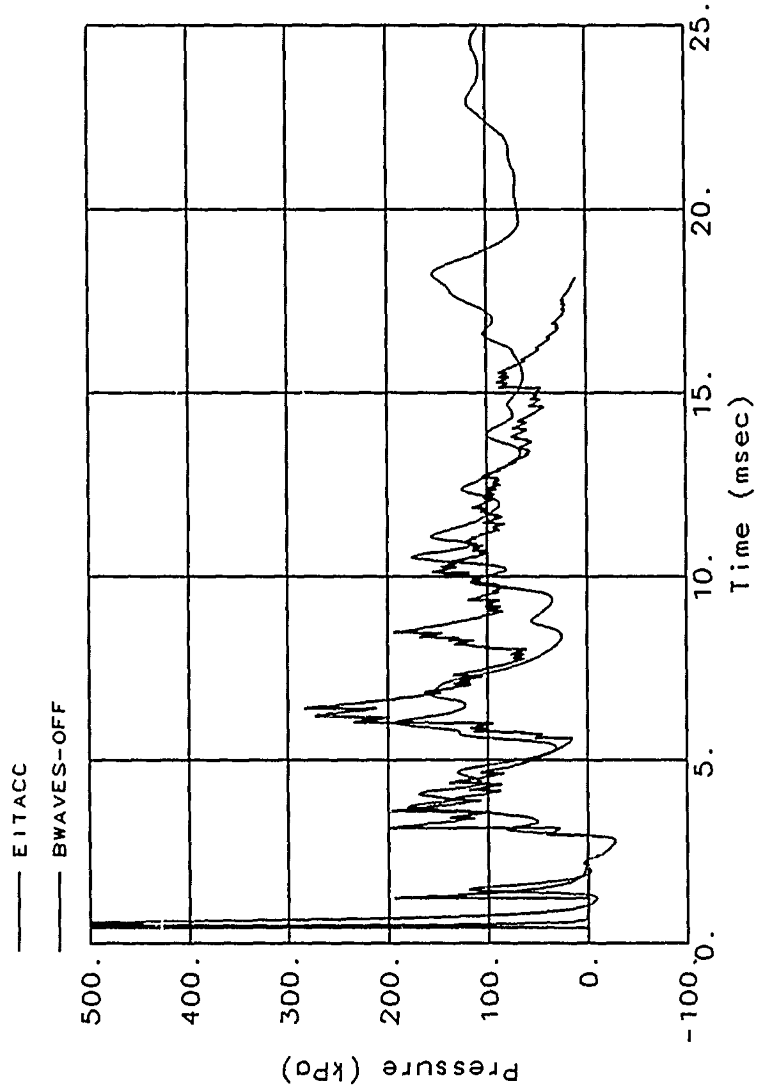
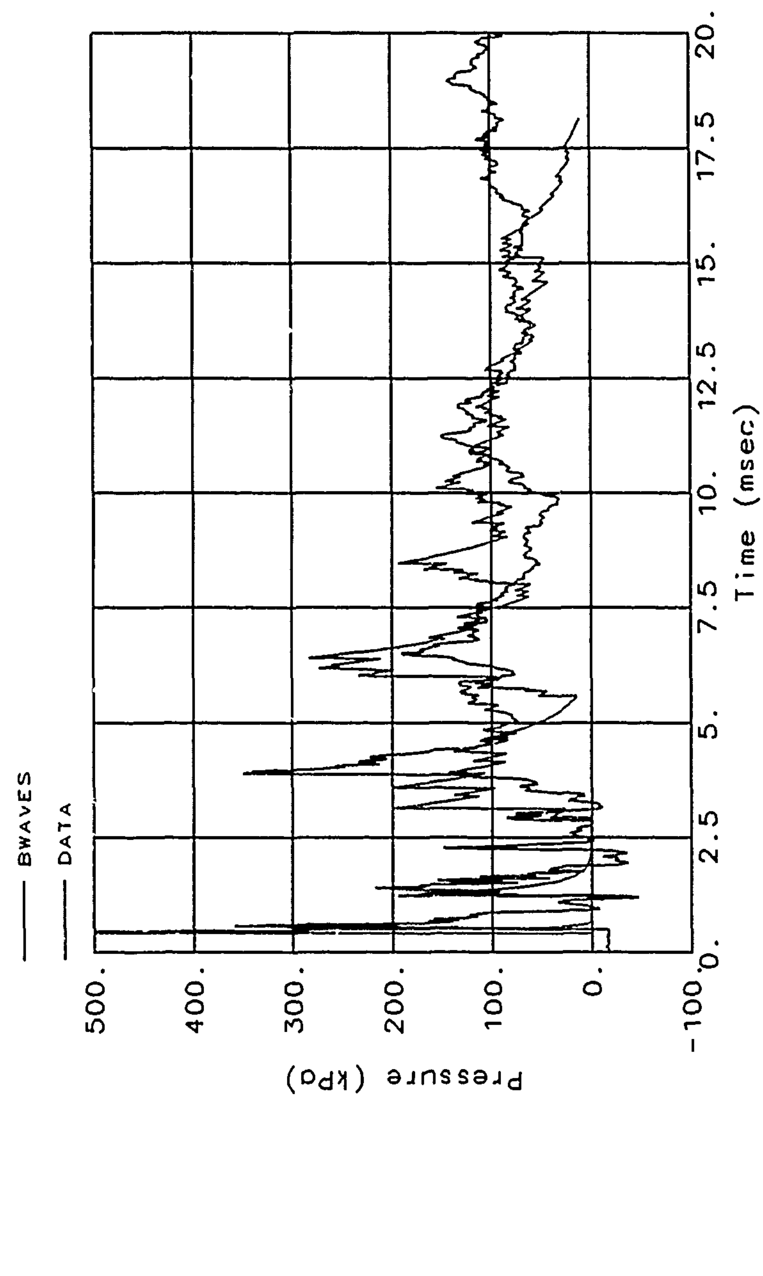
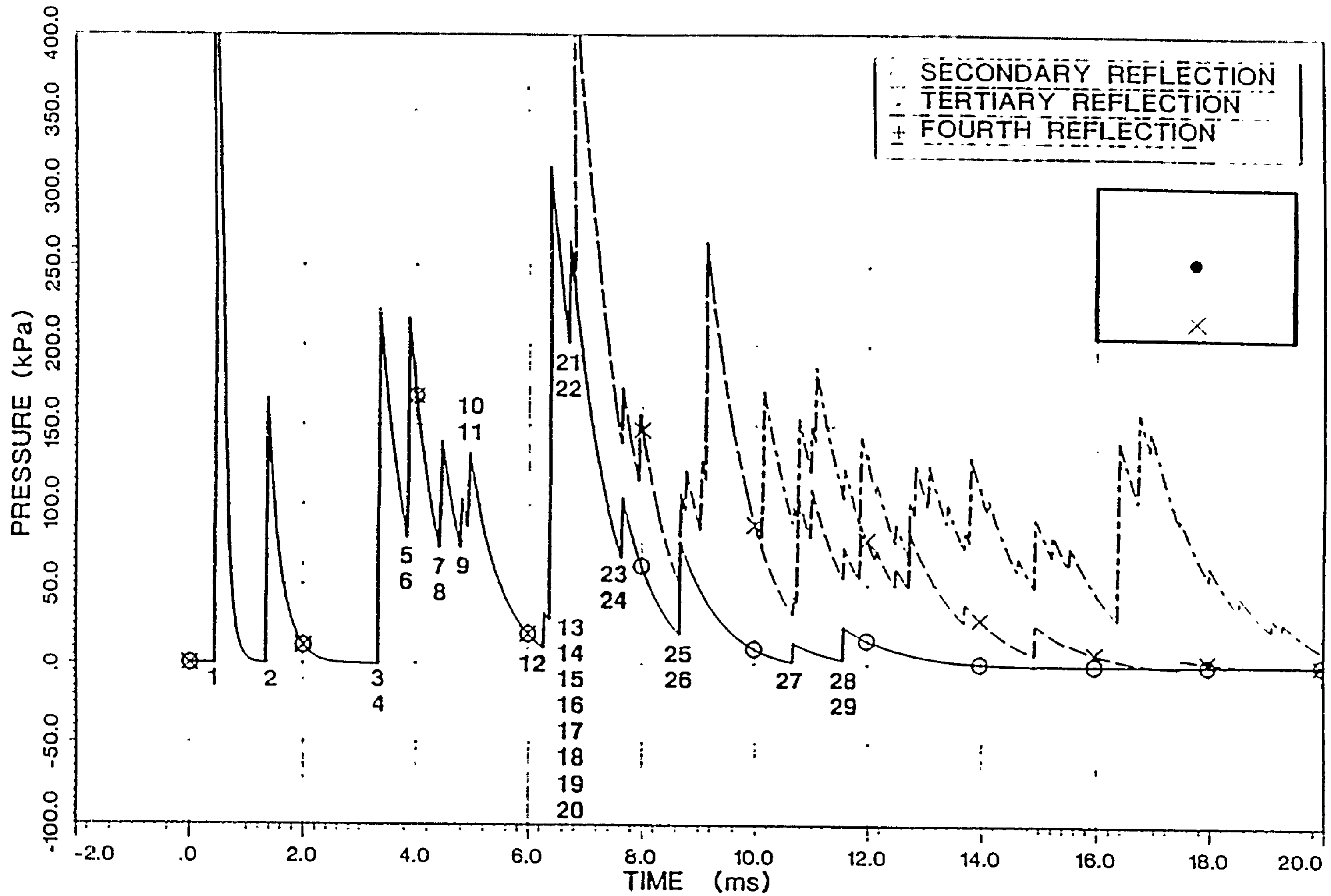


eibwoc.grf

JAYCOR


BWAVES
DATA
Pressure (kPa)
500.
400.
300.
200.
100.
0.
-100.
0.
2.5
5.
7.5
10.
12.5
15.
17.5
20.
Time (msec)

dabwoc.grf



1 Free Field, 2 Front, 3 Bottom, 4 Top
5 Bottom-Front, 6 Top-Front, 7 Left, 8 Right
9 Back, 10 Right-Front, 11 Left-Front, 12 Back-Front
13 Bottom-Right, 14 Bottom-Left, 15 Top-Right, 16 Top-Left
17 Right-Top, 18 Right-Bottom, 19 Left-Top, 20 Left-Bottom
21 Back-Top, 22 Back-Bottom, 23 Back-Right, 24 Back-Left
25 Bottom-Top, 26 Top-Bottom, 27 Front-Back, 28 Left-Right
29 Right-Left

Figure 8-2. COMPLX results for front sensor, 1 lb C4 in bunker.

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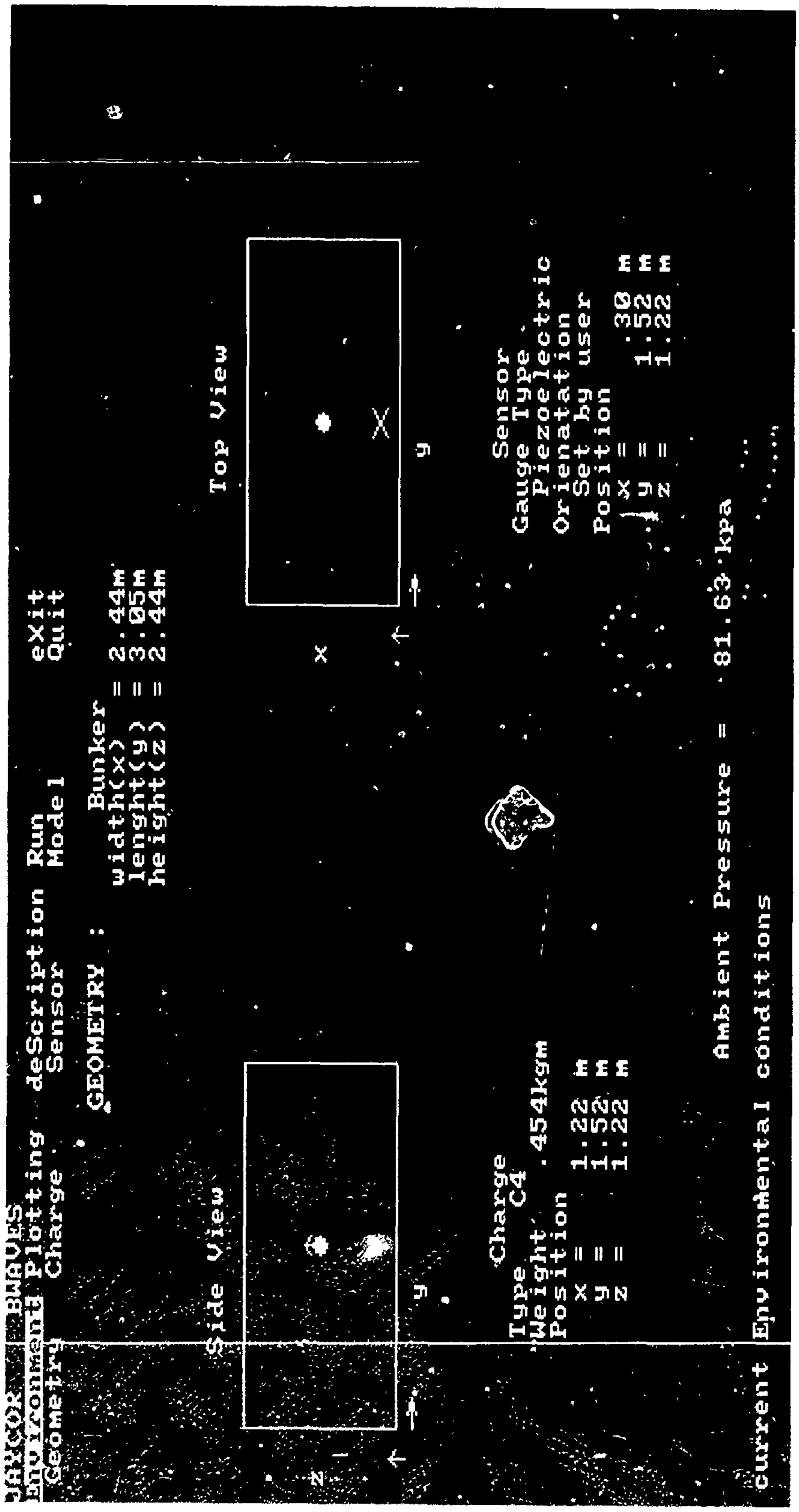
BWAVES
Environment Plotting deScription Run eXit
Geometry Charge Sensor Model Quit
GEOMETRY :
Bunker
width(x) = 2.44m
lenght(y) = 3.05m
height(z) = 2.44m
Side View
Top View
Charge
Type C4
Weight .454kgm
Position
x = 1.22 m
y = 1.52 m
z = 1.22 m
Sensor
Gauge Type
Piezoelectric
Orienatation
Set by user
Position
x = .30 m
y = 1.52 m
z = 1.22 m
Ambient Pressure = 81.63 kpa
Current Environmental conditions

Task 2. Complex Waves

PREDICTION ASSESSMENT

Data

- Gauge response is sometimes questionable
- Non-ideal explosion characteristics seen

EITACC

- Qualitatively good agreement
- Substantial spatial resolution required
- Best candidate for incorporating all phenomena

COMPLX

- Offers insight into structure of complex wave
- Demonstrates sensitivity of gauge location
- Areas for improvement: non-ideal wave, thermal effects, gauge response

Product: Topical report, upgraded BWAVES

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Task 2. Complex Waves

WHAT IS IMPORTANT

- Sensor Location
  - Small changes in position can change wave interaction
- Sensor Orientation
  - Affects amplification of reflected waves
- Sensor Response Characteristics
  - Affects pressure interpretation
  - Largely undocumented
- Venting
  - Changes pressure in local region immediately
  - Affects pressurization and reflection at later time
  - Changes effective propagation speed (temperature)

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TASK 3. COMBINED INJURY

Extend pathology database to GI injury

Evaluate importance of blast on battlefield

Estimate medical and performance consequences

Products: **Reports**
Expanded database
Combined injury model software

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The USANCA Question

What is the Distance at a given Yield beyond which

a commander can be	99% confident
that troops in an	exposed, unwarned condition
engaged in	physically demanding tasks
will experience less than	5% incidence
of more than	75% performance decrement
within a period of	30 days?

The Combined Injury Question

Will incorporating combined injury effects increase this distance by at least 100m?

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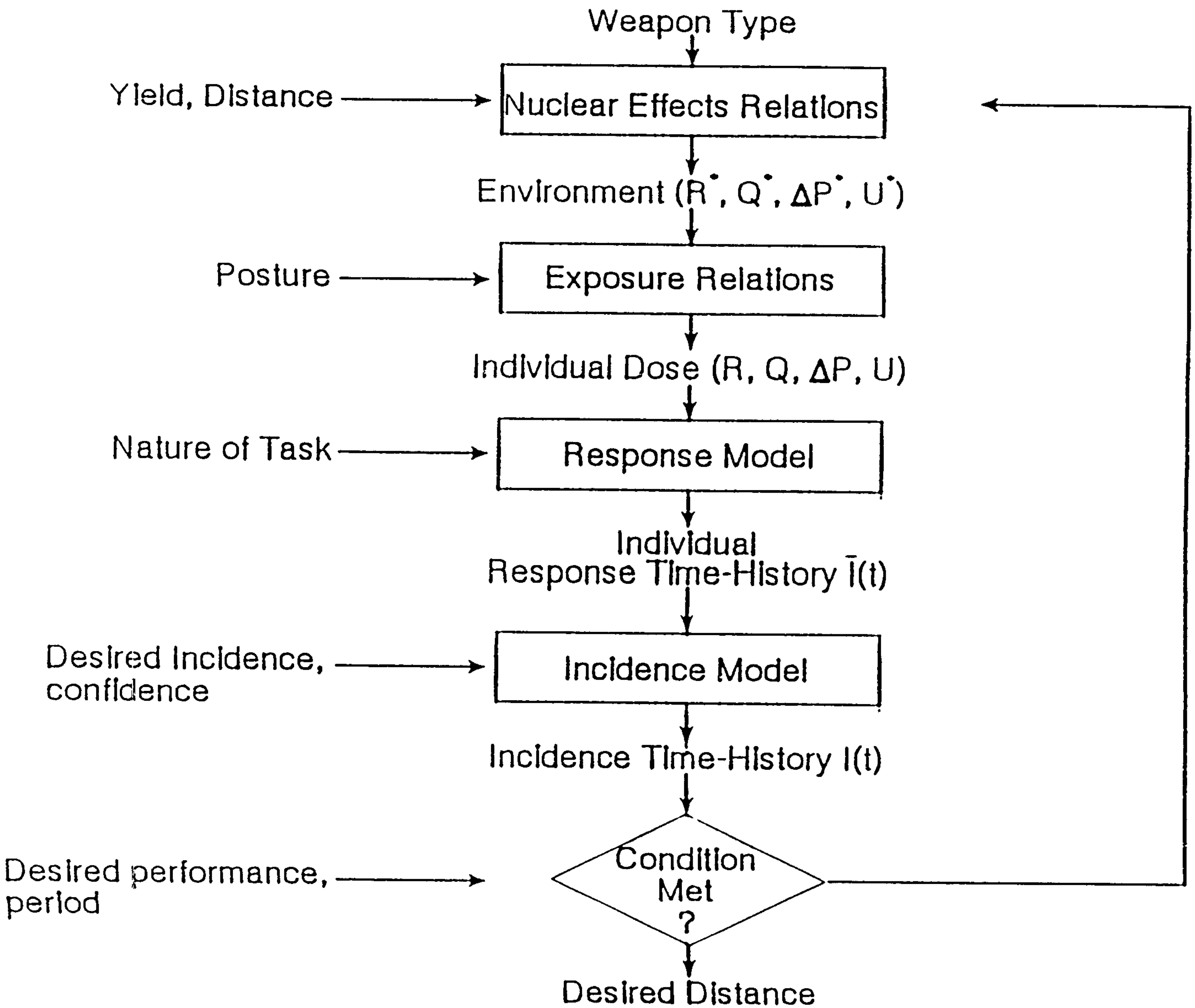
THE ALGORITHM FOR THE SOLUTION



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COMBINED INJURY MODELS

Dominant Effect Model

$$I_D(t) = \max\{I_{rad}(t), I_{burn}(t), I_{blast}(t)\}$$

Statistical Effect Model

$$1 - I_s(t) = [1 - I_{rad}(t)][1 - I_{burn}(t)][1 - I_{blast}(t)]$$

Compounded Symptom Effects Model

$$I_C = f[S_{rad}(t) + S_{burn}(t) + S_{blast}(t)]$$

Mechanistic Models

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MECHANISTIC MODEL

Dynamic Equations

$$\frac{dP}{dt} = -B + \frac{A}{T_h}(1 - P)$$

$$\frac{dB}{dt} = \left[\frac{dB}{dt}\right]_O - \frac{A}{T_f}B$$

$$A = \frac{1}{1 + t/T_i}$$

Time-Varying Quantities

P = performance

B = "infection" agent

A = "antibody" concentration

Characteristic Time Constants

T_h = "healing"

T_f = "fighting"

T_i = compromise of "immune" system

"Opportunistic" Infection Rate

$$\left[\frac{dB}{dt}\right]_O$$

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SELECTION OF PARAMETERS

Initial Conditions

$P(0) = 1$ (perfect health)

$\left[\frac{dB}{dt}\right]_o = 0.0001$ (arbitrary)

Biological Time Constants

$T_f = 3$ hrs

$T_h = 500$ hrs

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SELECTION OF PARAMETERS (Cont'd)

Calibration of Burn Insult ($T_i = 0$)

15% area, 2°: $B_o = 0.33$

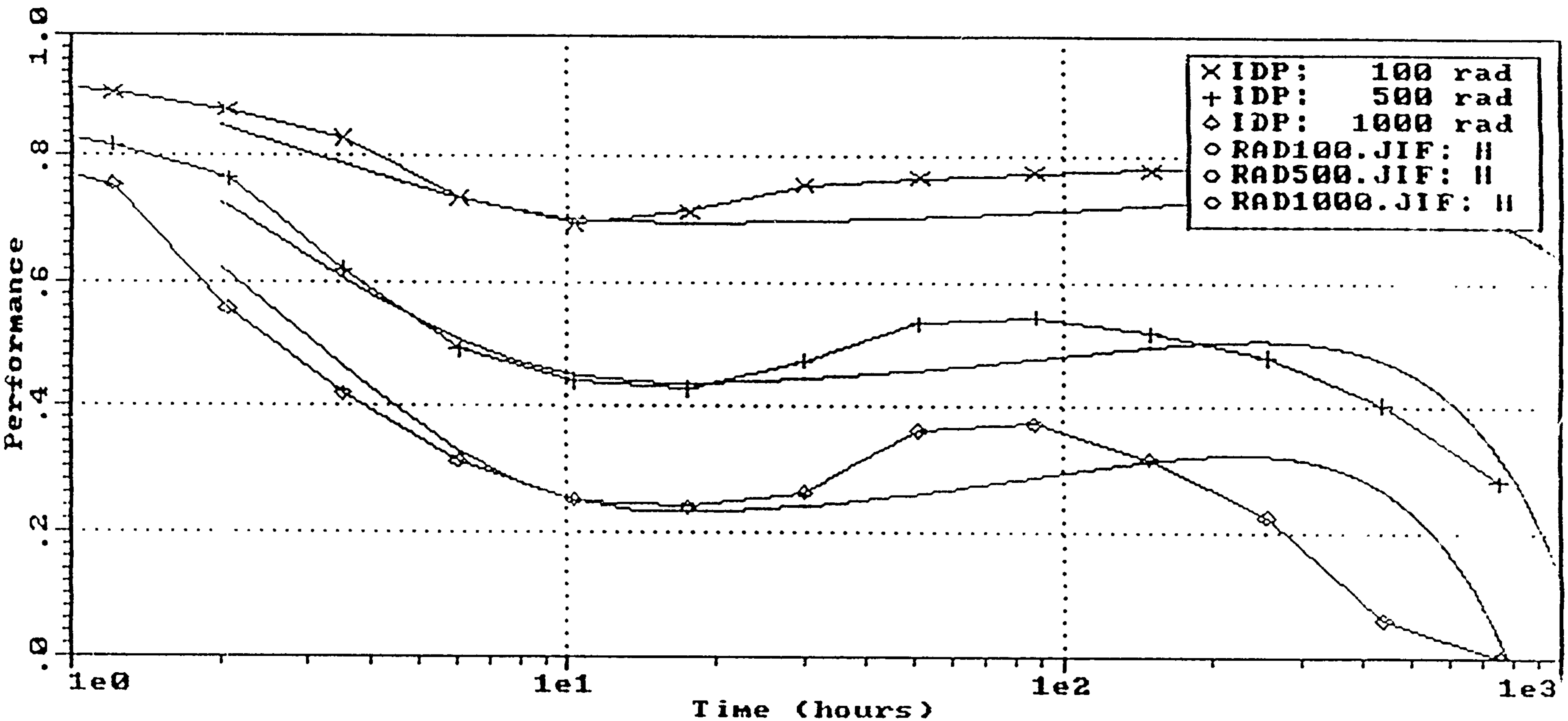
25% area, 2°: $B_o = 0.68$

35% area, 2°: $B_o = 0.84$

Calibration of Radiation Insult

R = 100 rad	$B_o = 0.30$	$T_i = 1000$ hrs
R = 500 rad	$B_o = 0.55$	$T_i = 300$ hrs
R = 1000 rad	$B_o = 0.75$	$T_i = 200$ hrs

CALIBRATION AGAINST RADIATION



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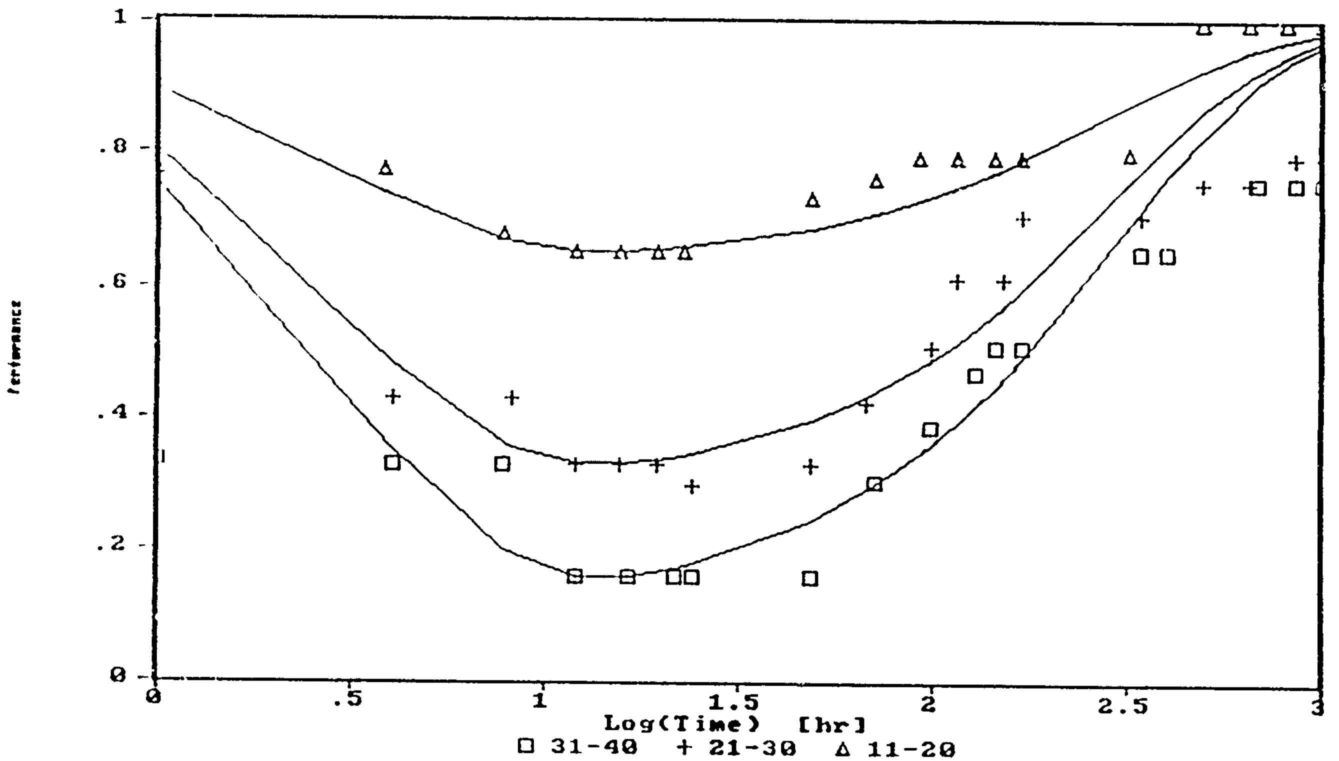
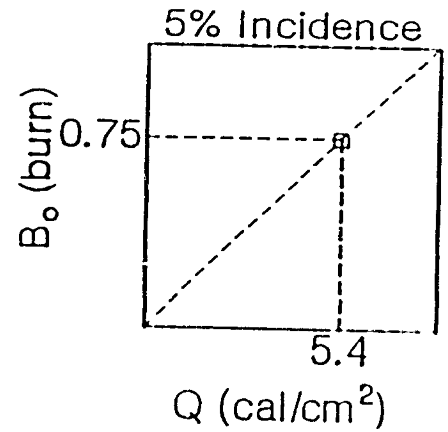
INDIVIDUAL INCAPACITATION DUE TO BURN





$$I = B_o(\text{burn}) \frac{\exp\{-t/T_f\} - \exp\{-t/T_h\}}{F(T_F, T_H)}$$

$P = 1 - I$; $T_f = 3$ hr; $T_h = 500$ hr

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DELIVERABLES

REPORTS

Pathology Database
- ○ Reorganized materials
- ◐ Users' manual for software
- ◐ Findings

Injury Modeling (Free-Field)
- ○ URT
- ○ FEM sheep thorax model
- FEM human thorax model
- Generalized model validation

Complex Waves
- ● EITACC results
- ○ COMPLX results
- Injury predictions

Combined Injury
- ○ Blast importance on battlefield
- Biological response model

○ Working document
● Delivered

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DELIVERABLES

SOFTWARE

- ● Pathology Database
- ● BWAVES
- ● INJURY
- ● ACCESS
- ○ ADINA® sheep thorax model
  ADINA® human thorax model
- ◐ Combined Injury

- ● POST
- ● JAYPAD
- ○ PACMON-2

○ Working document
● Delivered

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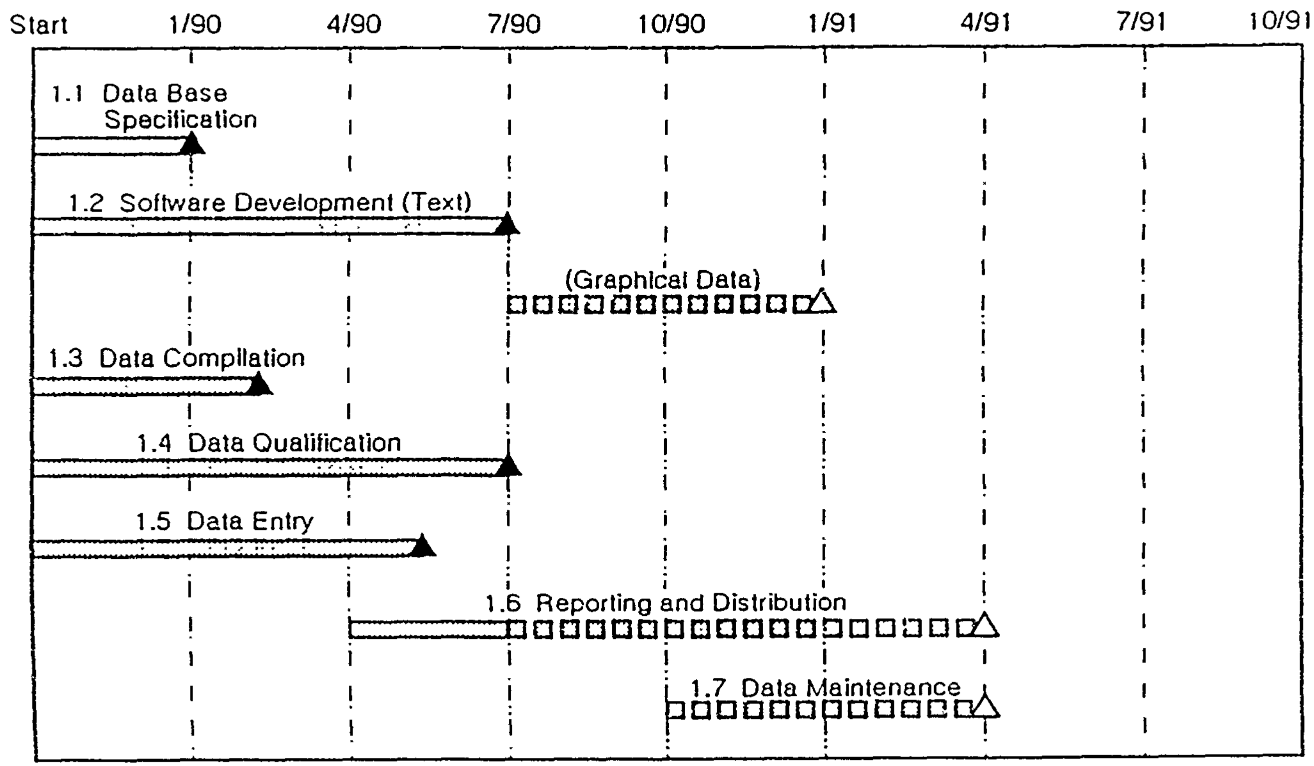
SCHEDULE

Research Topic 1: Pathology of Lung Injury

Task 1. Construction of Pathology Data Base



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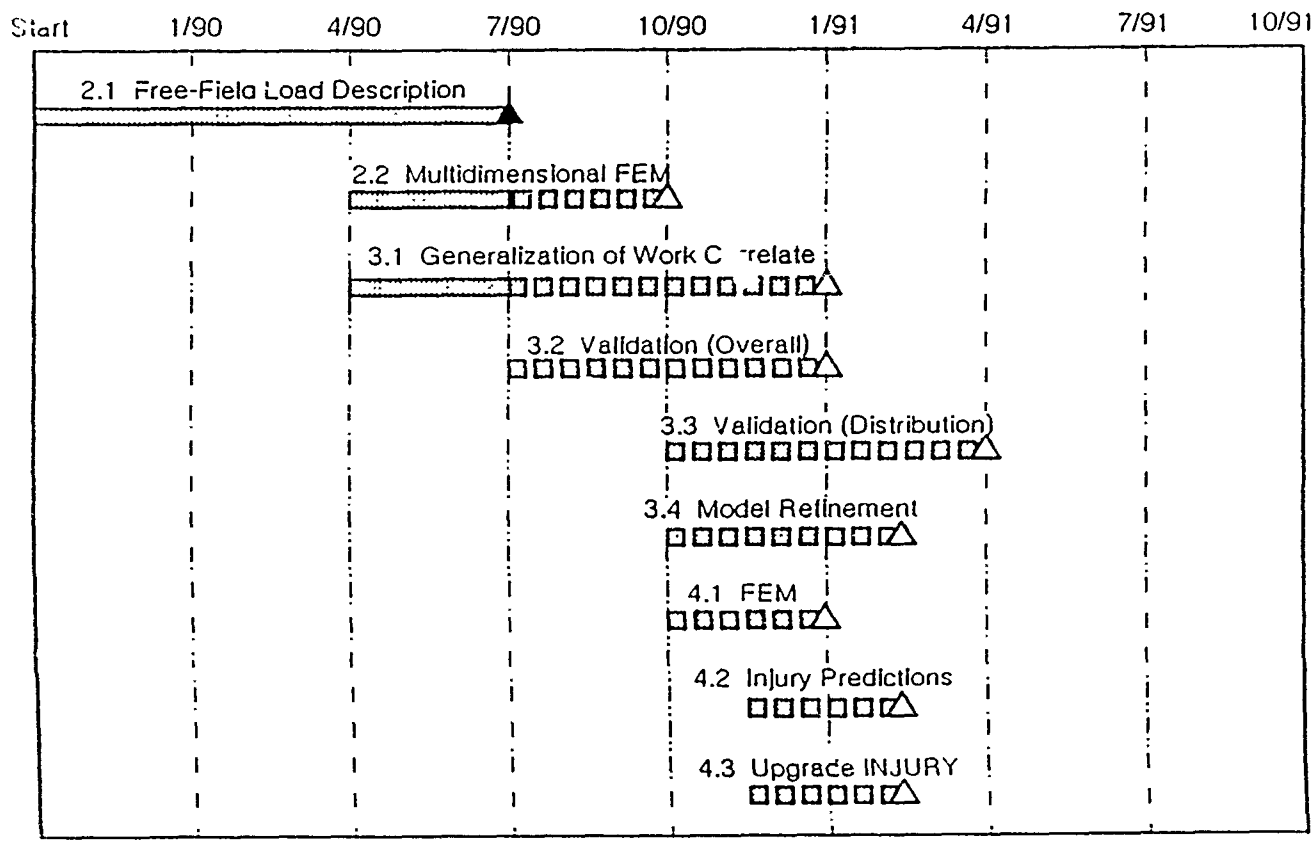
SCHEDULE

Research Topic 1: Pathology of Lung Injury

Task 2. Multidimensional Model of Thorax Response
Task 3. Validation Against Pathology Data Base
Task 4. Human Thorax/Lung Model



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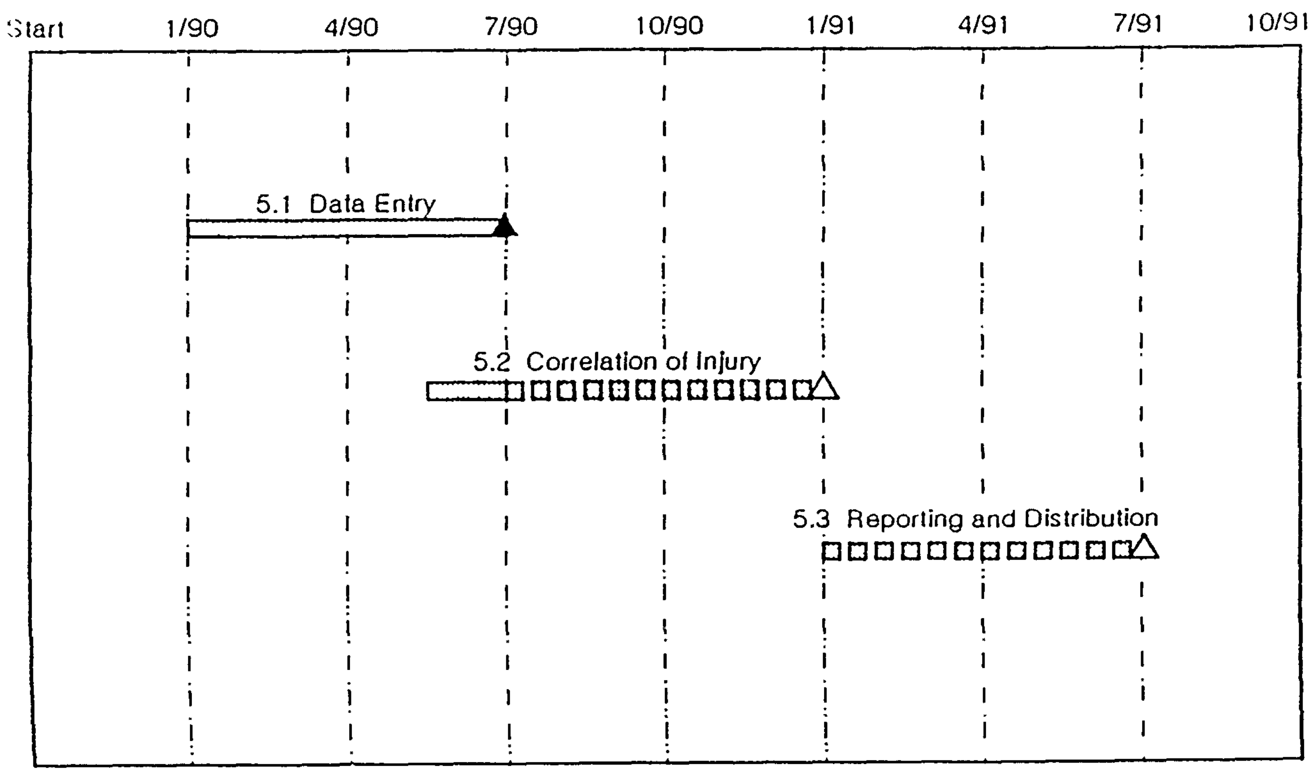
SCHEDULE

Research Topic 1: Pathology of Lung Injury

Task 5. GI Injury Data Base



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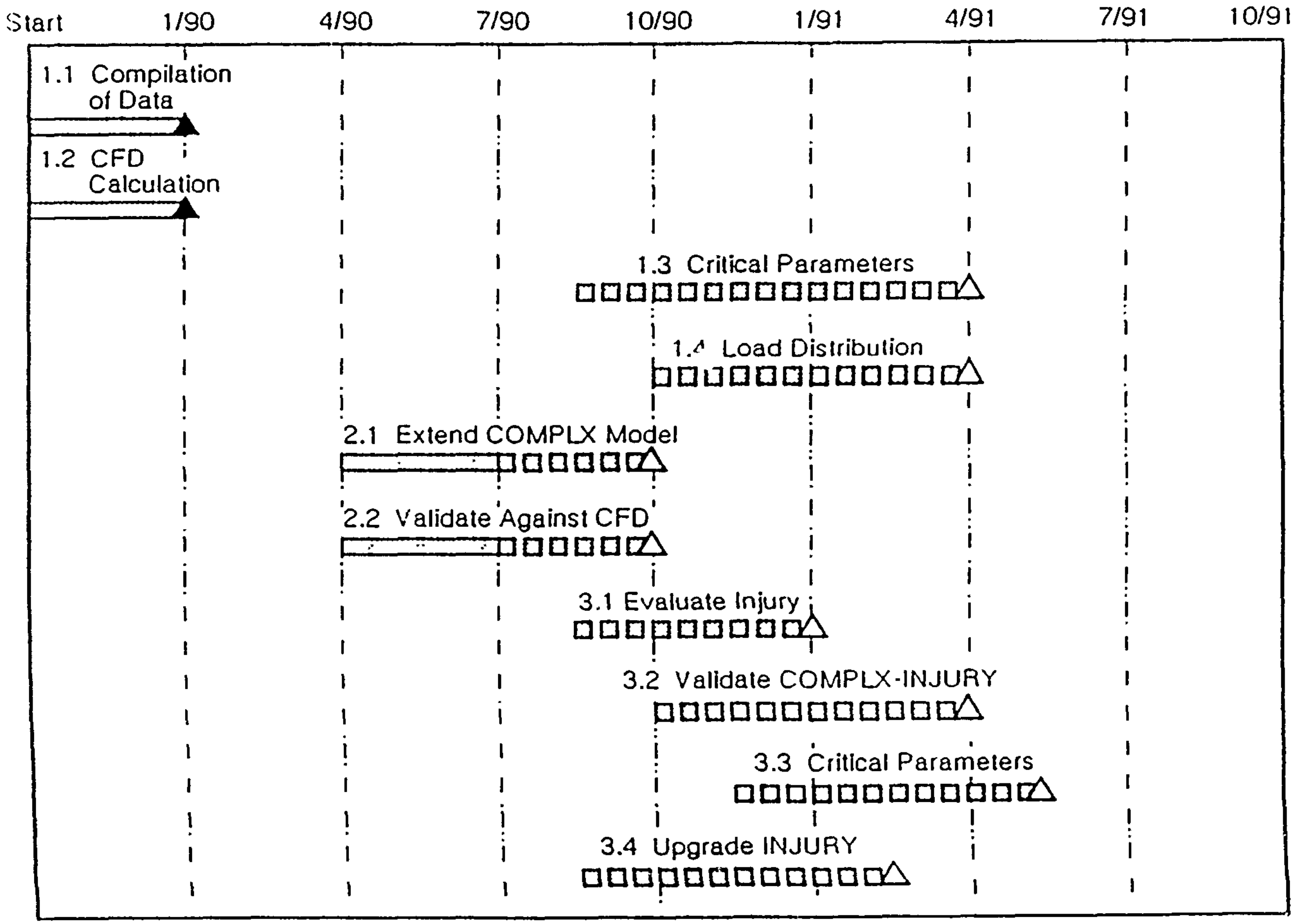
SCHEDULE

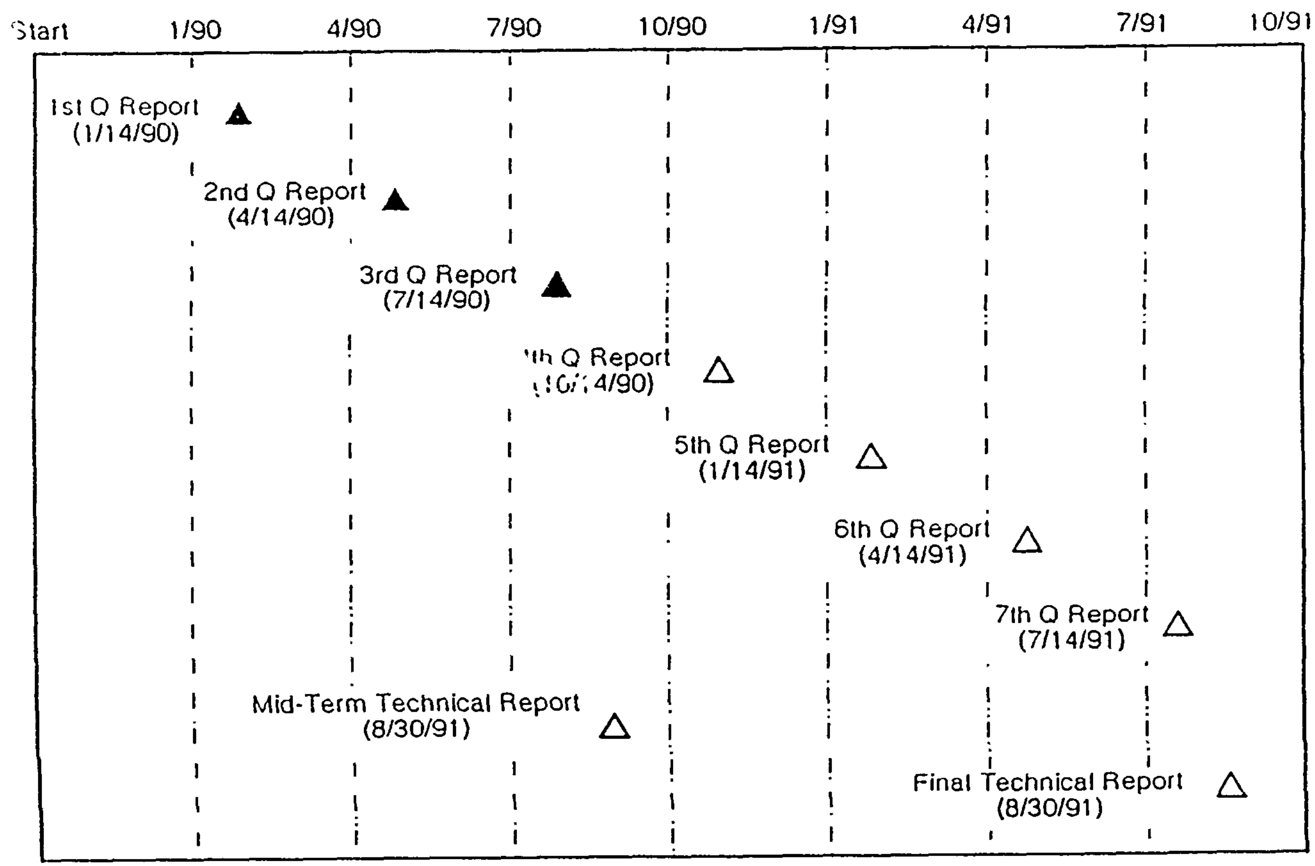
Research Topic 2:
Critical Parameters of Complex Waves

Task 1. Description of Complex Waves
Task 2. Extension of COMPLX
Task 3. Parameters of Injury



SCHEDULE

Reports



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SUMMARY

Pathology Database

- Completed
- Reorganized hardcopy ready to ship
- Software delivered to WRAIR
- Injury statistics determined

Biomechanical Modeling

- FEM sheep thorax model near completion
- Generalized model validation underway
- INJURY software delivered to WRAIR

SUMMARY (Cont'd)

Complex Wave

- Data analyzed with EITACC and COMPLX
- Model refinement identified
- BWAVES software delivered to WRAIR
- Topical reports/papers being prepared

Combined Injury

- GI data in pathology database
- Blast effects in battlefield assessed
- Software delivered to DNA
- Biological response model under development